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The Effects of Hydrophobic and Hydrophilic Natural Organic Matter on Charged Ultrafiltration Performance

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The Effects of Hydrophobic and Hydrophilic Natural Organic Matter on Charged Ultrafiltration Performance

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Abstract

Membrane processes are increasingly used in drinking water treatment to meet more stringent water quality regulations. Ultrafiltration (UF) has been widely used for advanced water treatment to remove colloidal particles, pathogens, and some natural organic matter (NOM). However, due to large pore sizes, UF alone cannot remove the majority of NOM which can lead to disinfection by-products during the chlorination process. In the laboratory, a negatively charged membrane was used to increase the removal rate of NOM through the utilization of electrostatic interactions. The objective of this study was to investigate the effects of NOM hydrophobicity and hydrophilic properties on the performance of the UF process using membranes of different charges and then to study the effects of fouling on the membrane caused from these changes.

Acknowledgements

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1.0 Introduction

Clean (potable) drinking water is a basic human right. Developing potable water is an increasingly important topic as the world's knowledge of what exists within our water and the technology that can be utilized for the removal of hazardous matter develops. One problem that we consistently face is the ability to develop technology that is both powerful in adequately removing unwanted constituents while also making it feasible and affordable for developing and transitioning countries, the countries where resources are limited and where the technology is needed most.

This paper will focus on the technology of ultrafiltration. The prospect of this particular water treatment process is promising. It is a technology that can replace a multiple step treatment processes by saving space, equipment needs, and in the end cost. There are issues with this technology. The primary issue is the efficiency of the membrane to filter out natural organic matter. This paper will research a possible way to diminish the harmful effects that natural organic matter can have on water quality and then will focus on the potential effects the NOM can have on the membrane itself. The particular concern with the membrane is its ability to receive permanent damage from matter causing blockage within the membrane pores. This is known as fouling.

Theoretically, by applying a negative charge to the membrane, we should be able to effectively remove and prevent the problems that organic matter once caused. If this theory is proven to be successful, then new steps can be taken to developing this lab scale discovery into a process design that could move the world further towards achieving that basic human right that everyone deserves.

1.1 Project Outline

The goal of this project was to study ultrafiltration effects from membranes with and without charges. This study was broken up into several different parts. First was the water samples that were used. The focus of this experiment was around NOM since that is the contaminant that caused the most damage in filtration. For the study of NOM the

research was broken into three parts consisting of raw water, hydrophilic water, and hydrophobic water. Next, for each of the water samples two membranes were tested. First a regular membrane, also referred to as a non-modified membrane, was used. Then while those were running through tests the other three membranes were being subjected to a chemical solution. This solution applied a charge to the membrane, which were then referred to as modified membranes. This was done to determine how a charge would affect the product or permeate water concentrations of different types of natural organic matter.

Each membrane had a series of different tests applied to it. These were broken up into the following measurements: the membrane hydraulic permeability, the initial flux, the flux during ultrafiltration, the rejection rate, and finally the electric potential of the modified membranes.

The membrane hydraulic permeability, L_P, is a measurement of the flux of the membrane using un-tampered water sample versus a range of pressures. This water will be referred to as ultrapure water. The flux is defined as the amount of fluid that flows through a unit area per unit time. The L_P was measured to gain an understanding of what is happening to the membrane during different stages of the filtration process. In the end this will be one of the best indicators for any permanent fouling that may occur due to NOM. The stages where this value is measured include the new membrane, after modification, pre-adsorption, after filtration, and after cleaning. The new membrane step is the measurement taken immediately after the membrane is removed from its packaging and rinsed with ultrapure water. Next, the after modification step is the measurement for only the modified membranes. After we rinse the new membranes with ultrapure water, the membranes that are to have a negative charge are soaked in a chemical reagent for a selected amount of time. Once that is complete we again rinse it with ultrapure water and then measure the L_P at this stage of the process. Both the non-modified and modified membranes then need to soak in the water sample for 24 hours prior to the ultrafiltration test run. The pre-adsorption step is measured immediately before filtration begins and then after filtration step immediately after. Finally, the membrane is treated with both a

physical and chemical rinse, after which the L_P is measured for the final time. This step is referred to the after cleaning step.

Another unit of measure that was made was the initial flux. This is the measurement of the initial flux of ultrapure water at the set pressure of the experiment, 0.69 mega-Pascal (MPa). This pressure was chosen based off of previous experiments ran within the laboratory that determined that this was the optimum pressure for the selected membrane type. The membrane was a Regenerated Cellulous (RC) Membrane with a 25 millimeter (mm) diameter and a nominal molecular weight cut off limit (NMWL) of 30,000 (30 KD). This measurement was made before the L_P for each step of each membrane and provides similar insight as the L_P does.

The flux was again measured during the physical filtration process through a series of timed sample collections. This measurement allows a view into how the flux changes over a period of two hours. The time of two hours was chosen on the basis that typically after two hours the system reaches a steady state and any changes in flux would be minimal beyond that time.

From this a conclusion about the efficiency of the water filter was made. Additionally, a conclusion from the fouling of the filter was also made. Once both conclusions were drawn, a final design for a water treatment facility incorporating the new filtration technique was made.

2.0 Background

Water is essential to human life. Without it, we cannot survive and too many people currently do without. Each year more than five million people die from water related diseases [26]. More specifically, every 15 seconds a child dies from water borne diseases [3] and for children under five years of age, water related diseases are the leading cause of death [9]. There is no doubt of the value of a clean water source and the importance of potable water when it comes to saving lives. Furthermore, there are many social benefits related to clean drinking water. Access to safe drinking water has been shown through case studies to not just improve health but also enhance gender equality, promote sustainable development and alleviate poverty [15]. Although water is not the end all solution for the health and social issues that plague our world as a whole, it clearly has the ability to ease many of the problems that face us as we begin to develop as a world through the new millennium.

This paper will focus on the technology of filtration. However, before reviewing the experiment and its results, it is important to understand all of the elements that affect drinking water. These elements include the water to be treated and the technology used to treat it.

In 1984 an organization known as the World health Organization (WHO), filled with experts from around the world, developed guidelines to serve as a basis for water regulation standards for all countries across the world, particularly those countries whom didn't have the necessary resources required to gather and assess data involved with water treatment [36]. A full table of these standards can be seen in Appendix A. This was one of the first times the world united in terms of developing universal drinking water standards. This was a giant step towards establishing clean water as a topic of global importance and since then, the value of potable water has never left the top of that list. This project was done in collaboration between two universities, one from the United States and the other China. This collaboration between countries is crucial when the most likely leaders of this developing technology in the coming years is brought into perspective.

With large populations and financial wealth both China and the United States are countries that will have a major influence in politics and the direction of developing technology. There is little to no contest when it comes to comparing population figures of China to the United States and to the rest of the world. With a population of 1.322 billion people, China beats the U.S. by having well over more than four times the amount of people within its borders [9]. They are the country with the world's largest population [30]. By shear mass alone China holds such an important influence. Furthermore, the more people they have the more clean water is required to sustain their population and save their citizens. In the cities and urban areas, China has a set of improved water source (in percent of population in 2002) of 92 percent. This is a reasonable value, however, when that measurement is looked at in the rural regions of the country, the number drops down dramatically to 68 percent while the U.S. remains consistently at 99 percent or above in both categories [30]. Improved water source is defined as a legitimate water source with at least 20 liters per person to be available within one kilometer of the users dwelling. With a reasonable large portion of China's population stuck with limited water resources, the importance of ensuring what water they have access to is safe becomes of the greatest importance. And when it is of great importance to China, then the rest of the world must listen.

As for the United States, evidence of their influence over the world can be seen even in recent news. In 2007, the United States was ranked the number one country when it came to total gross domestic profit (GDP) at $13.8 trillion, which more than triple that of the runner up, Japan, who had $4.3 trillion [36]. Knowing that, it's no surprise that with the current financial crisis hitting American home life, other countries also feel the sting.

Fortunately the market for membranes seems to be unaffected by the financial troubles facing America. There are more than 250 microfiltration and ultrafiltration installations in operation within the United States. This is equivalent to over 1 billion gallons per day of treated water [23]. In fact, "the entire worldwide membrane market is predicted to grow from $7.6 billion in 2006 to over $10 billion in 2010, with a growth rate of 10 percent or greater for the foreseeable future" [23]. With the world economy

following suit and investing in the future of filtration as a resource for clean water operations, the technology is definitely on the rise of importance.

2.1 Water Purification Methods

Water purification is broken into several different stages; a primary stage, a secondary stage, and an advanced or tertiary stage are the three most commonly seen [22]. The primary stage is used for the removal of suspended solids which are the solids are large enough to be effected by gravitational forces. It is common so see coagulation, flocculation, and sedimentation/clarification in the primary stages of drinking water treatment. The secondary stage is used for the removal of organic matter and it consists of some sort of filtration. Finally, the tertiary stage is only used in some situations and it is comprised of advanced treatment for the removal of some other constituents such as nitrogen and phosphorus and then ends with disinfection. Disinfection can be achieved by any number of processes, from ultraviolet radiation to chlorine chemical additives. An example diagram of these process steps can be seen below in Figure 1.

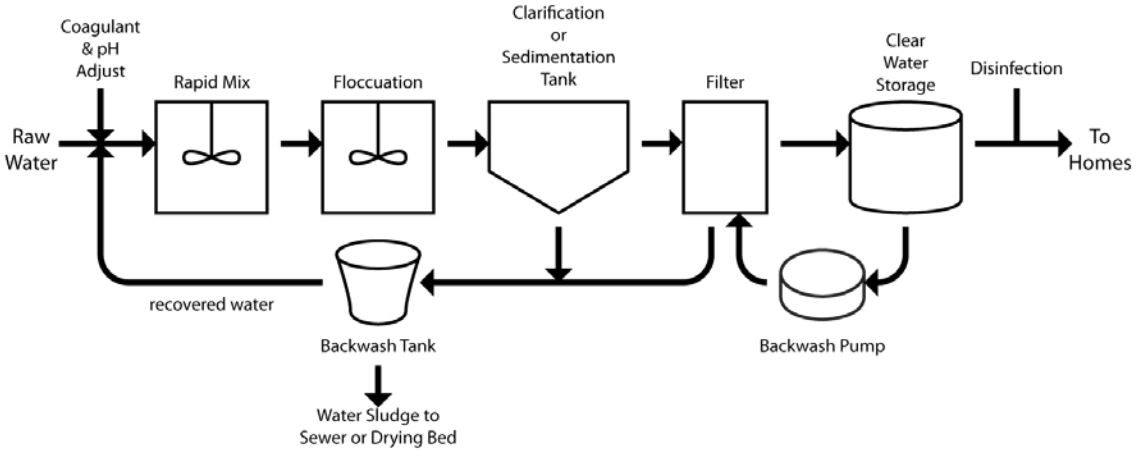

Figure 1: Generic Water Treatment Process

Before discussing ultrafiltration, a brief review of the various processes shown above and how they may or may not affect ultrafiltration will be provided.

2.1.1 Coagulation and Flocculation

The current conventional method of natural organic removal is coagulation and flocculation. Coagulation is the addition of positively charged coagulants, for instance, aluminum sulfate (alum) or a ferric salt, such as ferric chloride, are the two most commonly used coagulants [11].

Flocculation is the mixing under turbulent conditions of these colloids and coagulants in an effort to neutralize the charge and to help induce the Van der Waal forces within the particles. This causes the mixture to form interparticle bridging or polyelectrolyte compounds that can be either settled or flocked out of the water [11]. In effect, the combination of coagulation and flocculation changes some colloidal and dissolved particles into settleable ones so that they can be removed more easily from the water treatment process. This method requires more technology, space, utility streams, and the constant flow of a coagulant such as alum or ferric chloride. These additional constraints boost the cost and make it more difficult to supply clean water to regions with limited access to this technology or chemicals. With the use of a really effective filtration system, coagulation would no longer be needed and in fact, could actually hinder the process. According to a recent study, “Coagulation/flocculation can remove polysaccharide- and protein-like NOM.... However, if NOM fouling is hydraulically reversible, then coagulant addition may simply lead to added resistance and an associated decrease in permeability” [1]. This means that not only is the process less cost effective in comparison to just a filtration system, but also has the potential to be more inefficient.

2.1.2 Clarification and Sedimentation

The removal of suspended solids is almost always removed by clarification/ sedimentation. This is done by the use of the natural mechanism of the gravity. Solids with a high specific gravity will settle to the bottom of the tank while those with a lower specific gravity will rise to the top of the water [22]. Once they have settled the sludge from the bottom of the tank and the scum from the top of the tank are removed. An image of a clarifier is shown below in Figure 2 [14].

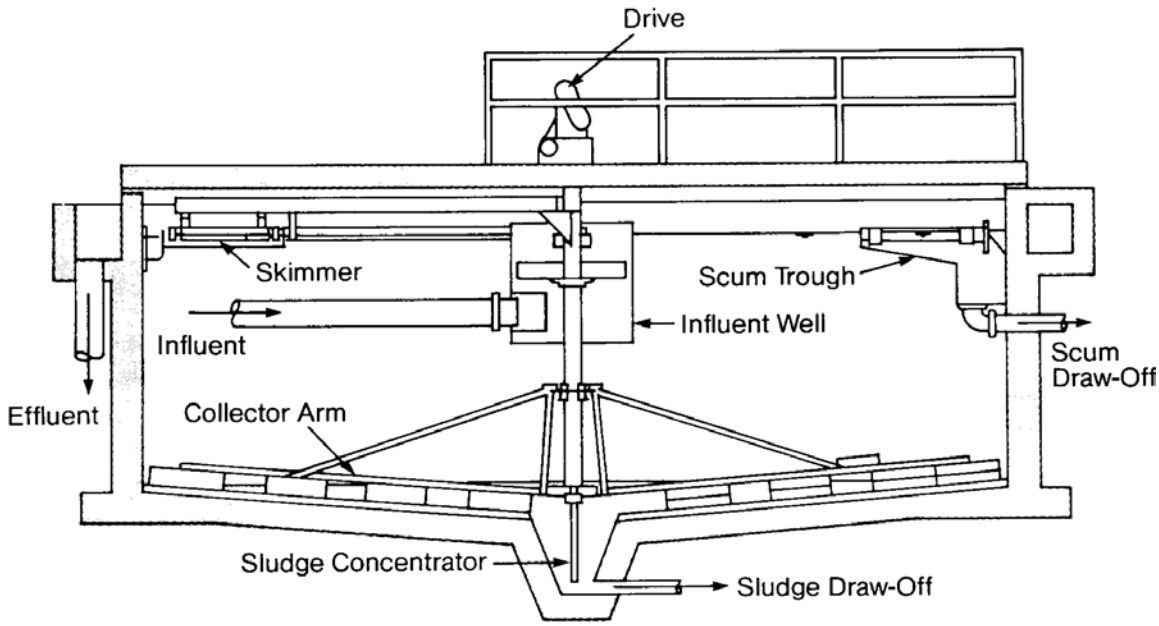

Figure 2: Sedimentation Tank Diagram

A skimmer rotates around the top of the water collecting scum which consists of grease and oil. A collector arm at the bottom of the tank repeats the same process collecting sludge which consists of dirt and mud and other large heavy items. Although this system is useful in cleaning water, this part of the process only removes large particles from the water and this alone would not make drinking water safe for consumption. However, in any water treatment process, whether it be a standard process or one that involves ultrafiltration, the addition of a simple sedimentation tank is always necessary and cost effective. For ultrafiltration, the removal of large suspended solids is important for the prevention of any unnecessary fouling that may occur otherwise.

2.1.3 Disinfection

There are three primary methods for disinfection that are in practice for water treatment. They consist of ozone, ultraviolet radiation, and the use of a chorine chemical additive. Chlorine is currently the most commonly used of these three processes because it is almost always the most cost effective method; however, recent studies have shown that chlorination has its drawbacks as well.

Ozone is a very reactive compound that is used in disinfection because of its powerful oxidation agent. The series of chemical equations for ozone formation is shown below [22].

$$O_3 + H_2O \rightarrow HO_3^+ + OH^-$$
$$HO_3^+ + OH^- \rightarrow 2HO_2$$
$$O_3 + HO_2 \rightarrow HO + 2O_2$$
$$HO + HO_2 \rightarrow H_2O + O_2$$

Ozone formation creates two radicals, HO_2 and HO, both of which are the active form in the disinfection process [22]. Ozone is a great disinfectant for multiple reasons. It is probably the most effective disinfectant of the three not only as a virucide, but also because of its ability to dissociate organic matter without any development of harmful byproducts. Although it is extremely toxic, it has little to no chance of being harmful to wildlife or human ingestion due to its rapid dissociation [22]. A table comparing the effectiveness of various disinfectants for *Giardia* is shown below [11]. The table shows how little ozone is required in comparison to other disinfection treatments in order to provide the same impact.

Table 1: Surface Water Treatment Rule Ct[a] Values for Achieving 99.9% Reduction of Giardia lamblia

Disinfectant	pH	Temperature, °C					
		≤1	5	10	15	20	25
Free Chlorine [b]	6	165	116	87	58	44	29
(2 mg/L)	7	236	165	124	83	62	41
	8	246	243	182	122	91	61
	9	500	353	265	177	132	88
Ozone	6-9	2.9	1.9	1.4	0.95	0.72	0.48
Chlorine Dioxide	6-9	63	26	23	19	15	11
Chloramines	6-9	3,800	2,200	1,850	1,500	1,100	750

a. *C* is in mg/L and *t* is in time.
b. *Ct* values depend on the concentration of free chlorine.

However, there are some drawbacks to this disinfectant as well. The partial oxidation of organic matter that can occur from ozone can lead to biological regrowth in the distribution system and since it dissociates so quickly, it has no residual for eliminating bacteria after its left the treatment plant [11]. Additionally, ozone must be

produced on site. The most common method of ozone production is through electric discharge. This method is a huge energy consumer and therefore very expensive to own and run [22].

Ultraviolet radiation is another method of disinfection. It is a physical rather than chemical method for disinfection. The UV waves from a light source penetrate the cell walls of microorganisms and damage its DNA. UV is valuable because it cannot form any disinfection byproducts. However, it is not effective against *Giardia* cysts [11]. Moreover, the distance over which the ultraviolet light is effective is very limited and must be applied to a thin film of water [22]. Again, due to energy consumption this method of disinfectant is expensive and therefore not widely used.

Of all of the chemical disinfectants, chlorine is the most commonly used throughout the world [22]. It can come in several forms, the major forms of which include chlorine gas, sodium hypochlorite, calcium hypochlorite, chlorine dioxide, and bromine chloride. In most forms chlorine is a far more affordable process than any other disinfectant. Furthermore, it has the formation of free chlorine which continues to disinfect as it travels through the distribution system. The major drawback to chlorine which has only recently been discovered is the formation of disinfection byproducts (DBPs) from natural organic matter.

DBPs include trihalomethanes, haloacetic acids, and other halogenated organics. In the United States, the EPA limits the total concentration of chloroform, bromoform, bromodichloromethane, and dibromochloromethane to 80 parts per billion (PPB) in treated water. This number is called “total trihalomethanes.” These are considered to be environmental pollutants and are carcinogenic. They may also cause cancer and nervous system complications under too much exposure [26]. Some of the proposed pathways of how these DBPs are formed can be seen in Figure 3 [39].

Since chlorination is the most widely used and most economical, it would be beneficial for effective removal of the majority of natural organic matter before it reaches the disinfection process, thus lowering the risk of DBPs.

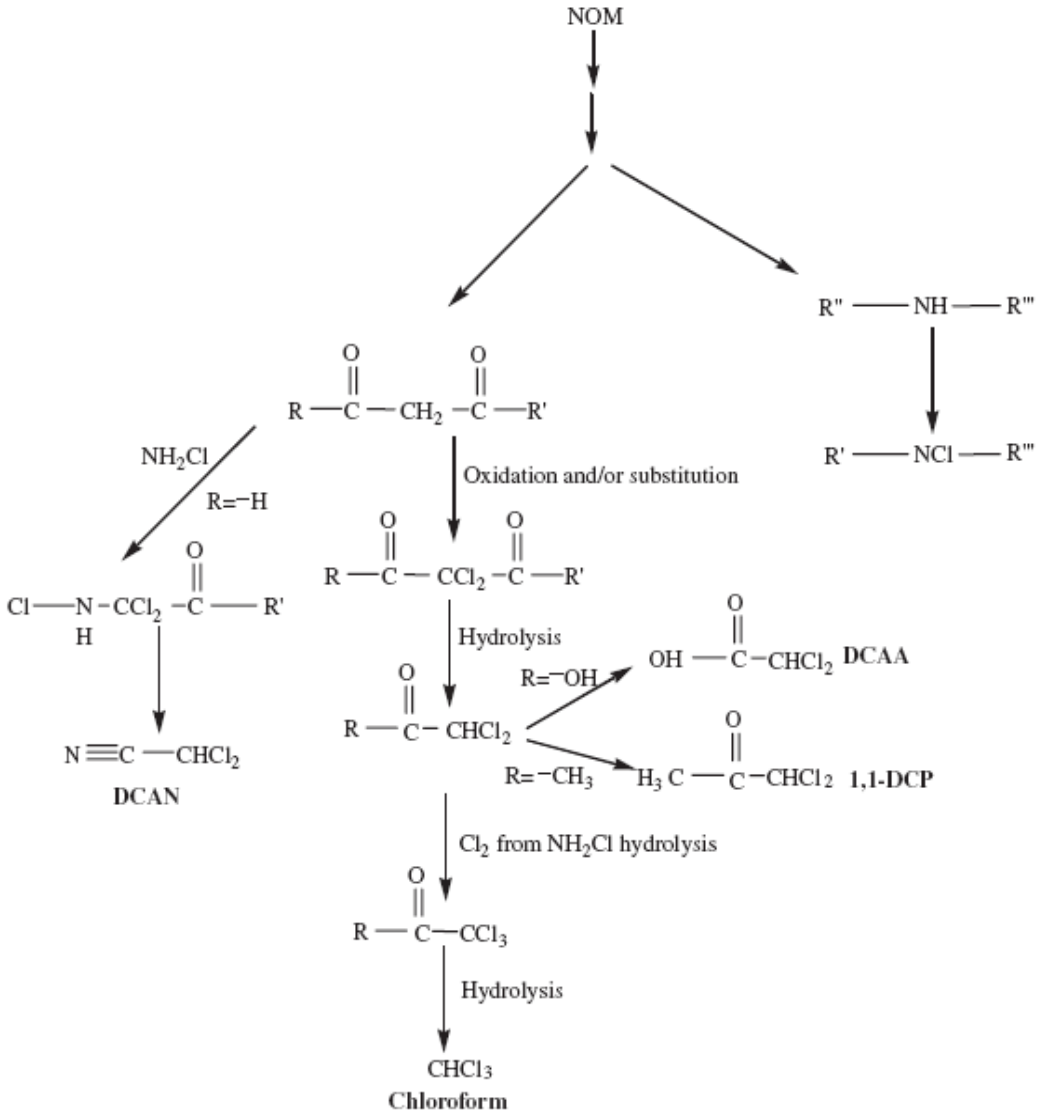

Figure 3: Proposed Pathways of DBP formation from NOM

2.1.4 Filtration Methods

Filtration was one of the first known methods for the production of potable water. In 3,000 B.C. Ancient Greece was using sand and gravel filtration methods for water purification. As our water process technology developed, so has our ability to understand what is inside of the water we drink. Now, by using the processes developed by our ancestors and the technology booming throughout the industry we can remove things that before we couldn't even see.

Membrane processes are increasingly used in drinking water treatment to meet more stringent water quality regulations [38]. Today, some sort of filtration unit is used in almost every water and wastewater treatment facility across the US. It typically follows after sedimentation and is used to filter out the particles that will not readily settle out via the forces of gravity. Membranes serve as a molecular sieve to separate solute molecules based on their size much like how a strainer works within a kitchen. Filtration typically removes fine particles, large microorganisms, and some bacteria. Filtration offers several advantages including greater water quality, easier control of operation, lower maintenance, and reduced sludge production [37]. Although the technology has such potential the critical factors limiting the use of membrane filtration for drinking water treatment are its efficiency and membrane fouling. Membrane fouling is the reversible and irreversible loss of system productivity over time [37]. The amount of fouling is caused by any number of things from various components within the untreated water or the type of filtration used.

There are several different types of membrane processes. Some examples include granular medium filtration, reverse osmosis, microfiltration, and ultrafiltration. Granular medium filtration is the filtration of suspended or larger particles from water. The removal of these particles is done through the use of a medium which can be constructed any number of materials from activated charcoal to sand [22]. This type of filtration is often seen in wastewater treatment systems where larger particles need to be removed. This method is less effective at removing colloidal or dissolved particles from water.

Reverse osmosis is a technology used for the removal of high concentrations of dissolved solids, primarily salts. This removal occurs by applying pressure in excess of the osmotic pressure of the dissolved components in the solution on one side of a semi-permeable membrane. This filtration method is less applicable due to the high cost associated with the substantial pressure requirements which would need a high pressure pump and the cost of the membrane itself [22]. Instead, this method is more commonly seen for small scale or desalination processes [23].

Microfiltration and ultrafiltration systems are pressure driven porous membrane operations [22**Error! Reference source not found.**]. Microfiltration allows the removal of particles, turbidity, and larger microorganisms. It is less successful for the removal of dissolved contaminants such as natural organic matter. Ultrafiltration can also remove waterborne viruses that are too small for microfiltration as well as much of the dissolved organic matter [37]. Using carefully chosen conditions for membranes, such as the material, pH, ionic strength, applied pressure, as well as others, it is possible to avoid fouling and even to retain molecules which are smaller than the pore diameter. In that case, the filtration system no longer acts as just a sieve, but rather a membrane [20].

2.1.5 Charged Ultrafiltration

Charged ultrafiltration is the use of an ultrafiltration membrane after it has been soaked in a chemical reagent that gives the membrane a negative charge. Ultrafiltration is one of the most effective membrane processes for water purification. The goal behind applying a charge to that membrane is to improve efficiency and reduce the amount of fouling on a membrane that can occur. Electrostatic repulsion of NOM by the membrane would in theory prevent water contamination and also absorption of molecules onto the surface of the membrane which would in turn prevent fouling.

The majority of natural organic matter, such as humus molecules, are anionic. Anionic means that the molecules in aquatic solutions at the pH range of naturally occurring surface waters are negatively charged [20]. The charge of natural organic matter was investigated in a study done by Childress et al. [7] for reverse osmosis. In their study the surface zeta potential of the reverse osmosis membrane decreased in the whole pH range (2-9) upon humic substances being adsorbed. This means that the humic solution that was being absorbed by the membrane was negative and caused the membrane charge to decrease as more of the solution bound itself to the membrane.

In order to have electrostatic repulsion, the membrane and the molecules must have like charges. Since the molecules are mostly negative, a negative charge to the membrane should also be applied. This was shown through an investigation held by Nyström et al. [25] using a positively charged filter. They filtered humic acid through 1.9

mm pore diameter inorganic capillary membranes. These membranes were not pretreated and known to have a positive charge. There was a rapid decline in flux during humic acid filtration. For example, the flux for a 10 parts per million (ppm) humic acid solution decreased by approximately 50 percent after 5 minutes of filtration, whereas, the flux for a 100 ppm humic acid solution decreased by more than 90 percent within 5 minutes, rendering the membrane essentially useless. They concluded that the reason for the fouling of the humic acid in their experiment was due to its binding tendency to multivalent ions. The negatively charged humic acid caused severe blockage of the positively charged membrane and its pores. This was again investigated briefly by Cho et al. [8] in their study on finding effective methods of improving the molecular weight cut off (MWCO) of a membrane. They found that the "effective MWCO for negatively-charged membranes with NOM was significantly reduced from nominal MWCO." This means that the size of the molecules that were passing through the membrane decreased when they had a negative charge, making the filter more effective.

This report will investigate ultrafiltration under a charged membrane. If a negative charge is found to have a significant impact on the filtration efficiency, the result will mean a reduction in the size and cost of the equipment needed for water purification. However, fouling is a constant concern for these filtration units, especially when that fouling is irreversible. Although it is known that a charge is effective in reducing fouling, the amount of fouling has previously not been quantified.

2.2 Potable Water Characteristics

The Yangtze basin which is the source of the water for this report is also the source water for over Four hundred million people surrounding it [34]. The Hangpu River is the river that directly feeds into Shanghai and accounts for over 70 percent of the water for the city [2]. All together the water system serves more than 12 million people in the city [28] With over ten water treatment plants in Shanghai and an average output of over 2.8 million meters cubed (m^3) per day or over 1 billion m^3 per year, the total annual domestic consumption of water, through water treatment facilities is approximately 450

million m^3 [28]. With all of this water being treated and consumed, the quality of the water becomes of great concern for the people of China.

This river system is also the source of large amounts of discharge. Many municipal wastewater facilities send their water into the same waters that the drinking water systems are trying to treat. The result of this is that organics and ammonia are thought to be the one of the main pollutants that treatment facilities must deal with [2]. Organic matter is difficult to remove and many times in the conventional treatment processes the matter will remain there afterwards. This was shown through research in the Shanghai area [2]. Tests were done at the Minhang Waterworks System where they revealed a rate of removal of over 99 percent of the turbidity and bacteria, but only 17 percent of the total organic carbons. These results went further, testing the concentrations at the pumping station and out of the tap. The results of the research can be seen below.

Table 2: Summary of Shanghai Water Constituents

Parameters	Raw Water of the Huangpu River (mg/L)			Effluent of the Minhang Waterworks (mg/L)			Removal Rate (%)
	Min.	Max.	Ave.	Min.	Max.	Ave.	
Turbidity (NTU)	32	47	38	0.09	0.15	0.11	99.7
TOC	5.1	6.8	5.7	3.6	6.6	4.73	17.0
UV-254 (cm^{-1})	0.137	0.233	0.184	0.079	0.104	0.089	73.3
Total Bacteria (CFU/mL)	360	2157	981	1	21	7	99.3

Water in the upstream of Huangpu River is polluted water. According to Chinese Environmental Quality Standard for Surface Water (GB3808-2002), the water is rated a grade IV water area. This means that the water is “only suitable for normal industry purpose or entertainment purpose not directly contacting human body” [2]. This means that the water isn’t even suitable for swimming. This same water is what the municipal water treatment facilities have to clean up before sending it through the distribution systems into families’ homes and into their tea.

There are solids within water and it is important to understand what they consist of and why they need to be removed. Solids within water can be broken up into three general categories: dissolved, colloidal, and suspended. Suspended particles are in a

separate phase from water. They are larger than colloidal particles and most often will settle out of the solution in sedimentation process of water treatment [11]. Since they are easily settled out and removed, they will not be the focus of this paper. Colloid particles are solids that range in size of 1 to 100 nm in diameter. They are particles that are small enough that their characteristics and movement are defined by molecular forces rather than larger forces such as gravity [11]. Dissolved particles are in solution forming a homogeneous phase with water and most often will pass through any filter [11]. In the case of drinking water filtration the colloidal particles effect the reversible fouling of filtration by reducing the membrane permeability through accumulation of solutes on the membrane surface through precipitate formation [2]. On the other hand, dissolved organic materials may cause irreversible fouling by altering the effective membrane within its pores by slipping into the membrane and precipitating out of solution with inside [40].

2.2.1 Colloidal and Dissolved Particles

Colloidal particles are particles that are so well mixed and dispersed within a substance that they give the appearance of being in solution when they are in fact only suspended. A commonly used example of a mixture with colloidal particles is milk. Much of milk is filled with the sodium salts and fatty acids derived from animal fats [5]. When you look at a glass of milk the color is white because these fatty acids are evenly distributed throughout the liquid rather than just sitting on the bottom.

The reason that these particles don’t settle or aggregate easily is because they are colloidal and therefore stay suspended through electrostatic stabilization. Electrostatic stabilization is the suspension of particles through the mutual repulsion of like charges, such as the polar water molecules and NOM. The particles are typically so small that the ratio of their surface area to their mass is much larger which therefore causes the characteristics of the surface area to play the dominate role in the behaviors of the particles. This means that the Van der Waals force is essentially the force in control of the particles motions and behaviors. The Van der Waal forces include attractions between atoms, molecules, and surfaces and are caused by correlations in the fluctuating

polarizations of nearby particles.

The colloids, which are most commonly negative in charge, will form a double layer of charge due to their electric potential. The first layer, the stern or fixed layer, will be all positive while the second layer, the diffusion ion layer, will be a general mix of ions, both negative and positive but will be mostly positive overall. An illustration of the electric potential of a typical particle can be seen in Figure 4.

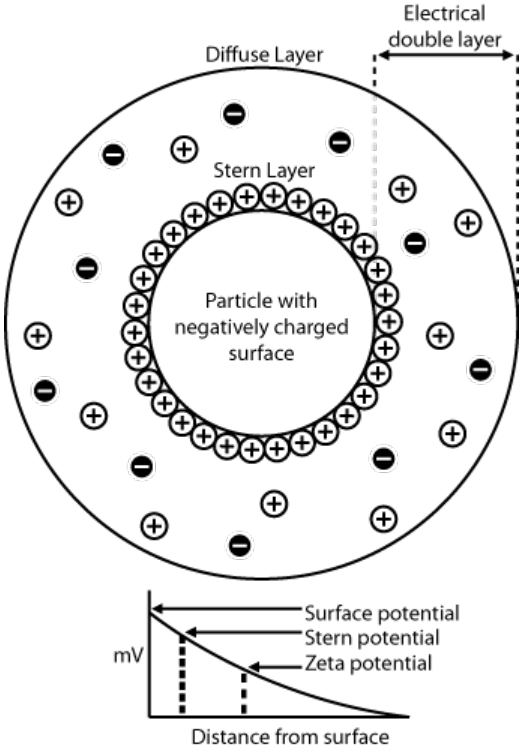

Figure 4: Diagram of electric potential versus the distance

The polarization of these particles is what keeps it within the water. Therefore so the best way to combat these compounds is to neutralize their charge so that they no longer will have that repulsion that keeps them suspended and therefore can be removed effectively.

The reason that colloidal material is an issue in water treatment is because it may cause fouling on a membrane by forming a cake on the surface [2]. In fact, according to one report [2], their results indicate that for low-turbidity and high-NOM surface water, colloidal material determined the rate of fouling. However, the fouling caused from

surface buildup is known to be reversible. Reversible fouling is just temporary fouling of the membrane which can be treated through either backwashing the system or using a chemical solution to rinse the membrane out. On the other hand, the fouling caused by dissolved particles within the water is often irreversible. This means that permanent damage to the membrane occurs which causes the filtration to be slow and in turn causes an ineffective form of water treatment.

Dissolved particles are smaller than one nanometer in diameter and are considered to be bonded in solution with water and therefore much harder to remove through typical treatment processes. In particular, dissolved organic matter has been shown to be one of the most important factors controlling the bioavailability of certain contaminants in freshwater sources.

This part of the solids within water is of great concern with not just filtration, but also charged filtration. This is because the dissolved matter is thought to be the cause of more permanent fouling by precipitating at the membrane surface or adsorbing within the membrane pores [4]. Since it is smaller, it can escape or travel through the pores of a membrane more readily than suspended or colloidal material. If using a charged membrane is shown to be successful, it will be because of its ability to filter out dissolved matter.

2.2.2 Protozoa, Bacteria, and Viruses

The main reason that solids should be removed from drinking water is because some of those solids may in fact be living. Solids can also appear in the forms of protozoa, bacteria, and viruses. These living organisms can cause serious health issues if consumed and may even lead to death.

Below in Table 3 is a list of commonly found organisms in untreated wastewater. These are the organisms that one doesn’t want to find in their drinking water. One thing that is important to notice is the concentration of the organisms. For example, cryptosporidium causes a diarrheal disease. Diarrhea is a serious concern because it is the cause of 30 percent of water related deaths and that percentage is even greater among

children [26]. A total of 1.8 million children die from diarrhea every year [3]. Cryptosporidium exists in concentrations of water as low as 0.1 to 10 organisms for every milliliter of contaminated water. It is very hard to measure, let alone detect. In the case of drinking water, the concentration of total and fecal coliforms, which are much greater in concentration, should be down to zero in order to ensure that all other harmful bacteria and viruses are also removed.

Table 3: Commonly Found Microorganism in Untreated Domestic Waste Water

ORGANISMS	Concentration, number/mL
Total Coliforms	10^5 - 10^6
Fecal Coliforms	10^4 – 10^5
Fecal streptococci	10^3 – 10^4
Enterococci	10^2 – 10^3
Shigella	Present
Salmonella	10^0 – 10^2
Pseudomondas aeroginosa	10^1 – 10^2
Clostridium perfringens	10^1 – 10^3
Mycobacterium tuberculosis	Present
Protozoan cysts	10^1 – 10^3
Giardia cysts	10^{-1} – 10^2
Cryptosporidium cysts	10^{-1} – 10^1
Helminth ova	10^{-2} – 10^1
Enteric visus	10^1 – 10^2

Filtration is a process that is particularly suitable for the removal of suspended solids, especially bacteria and protozoa, such as Giardia and Cryptosporidium [4].

2.2.3 Natural Organic Matter

Organic Matter (OM) is made of compounds of carbon and other molecules. There are more known compounds of carbon than any other element except hydrogen. Natural organic matter is an area within organic matter that consists of carbohydrates, proteins, fats, and oils. Organic matter effects water through turbidity, color, taste, and

odor. It can cause equipment issues and creates biofilm on distribution pipes which leads to less clean water and the need to replace pipes more frequently. Furthermore, it can also have harmful effects through housing and feeding bacteria and viruses and by also reacting with other chemicals in the water to form dangerous carcinogenic compounds. Finally, it has been shown in previous studies to be the main component responsible for membrane fouling.

NOM can be broken up into a number of different subcategories. This report will focus on one set of subcategories in particular, hydrophobic (HPO) and hydrophilic (HPI).

Hydrophobic organic matter is organic matter that will not readily dissolve in water or other polar solutions [16]. The HPO fraction represents around 50 percent of the dissolved organic carbon do to the fact that it has a larger molecular weight than HPI [40]. Hydrophilic has the opposite meaning and tends to represent around 35 to 40 percent of dissolved organic compounds in surface water [40]. Because of HPO matter's major fraction in surface or ground it has been the focus of many studies in the past [19; 25; 34]. Although there is no doubt that hydrophobic interactions are influential when it comes to the performance of a membrane and it's flux decline, according Nilson et al., the results showed that hydrophobic matter exhibited a greater flux decline than hydrophilic [24]. However, newer research has been focusing on the effects and comparisons of hydrophobic matter with hydrophilic matter on filtration.

According to several more recent studies it was shown that the hydrophilic matter was the main source for determining the rate and extent of flux decline. Additionally, Lin et al. [19] performed a study on the effect of fractionated NOM and observed that it was rather the large-sized molecules of both hydrophobic and hydrophilic NOM components that caused worse flux decline then one versus the other. From Zularisam et al. [40], the high molecular weight of the hydrophilic component was the prime contributor to NOM fouling. This is because of polysaccharides which are bulky hydrophilic macromolecules that are predominating in nature [8]. These polysaccharides are prone to adsorbing on to membrane surface which is the cause of the membrane fouling [40]. The conclusion of

these studies showed that macromolecules from both hydrophobic and hydrophilic are the major components that foul up membranes for filtration but that hydrophilic organic matter effects the membrane in a more permanent manner.

One reason that natural organic matter needs to be removed from water is because it is the primary food source for bacteria and other microorganisms. This can be illustrated by the biochemical oxygen demand (BOD) phenomena which is a method for estimating the amount of bacteria and microorganisms within water through bottle testing. A general trend of what occurs with bacteria growth and organic matter consumption over time is illustrated in the graph in Figure 5.

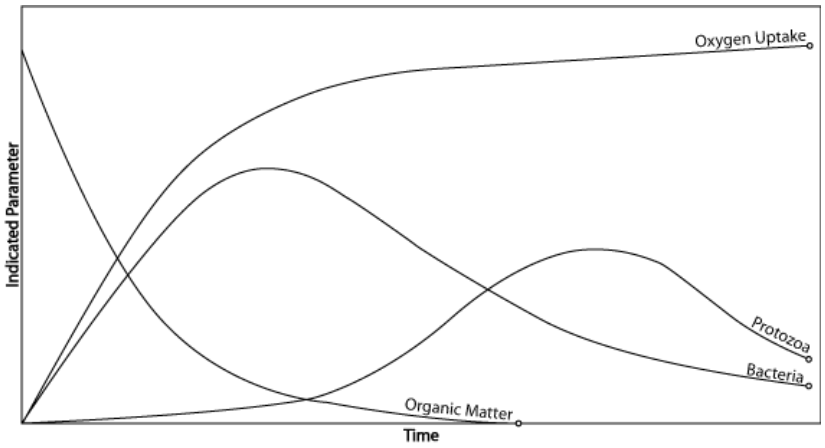

Figure 5: Consumption of Organic Matter versus Other Elements

From Figure 5, we can see that the excess of organic matter provides a food source for bacteria to thrive on, and once more, that creates more living things in the water supply, such as protozoa, which feed off of the living and dead bacteria. Limiting the amount of NOM that is within the water source initially can assure limited amounts of contamination from bacteria and protozoa.

Lastly, as previously mentioned, natural organic matter is an area of concern within water treatment because of the disinfection by-products during the chlorination. These byproducts are carcinogenic and may cause cancer under repeated exposure. Organic matter is the major source that contributes to the formation of DBPs during water treatment [39] and therefore needs to be effectively removed to ensure the safety of the water to be consumed.

3.0 Charged Ultrafiltration Procedure

3.1 Equipment

The equipment used in this laboratory is as followed.

- Regenerative Cellulous (RC) Membrane
- Glass Bottle with a Ground Glass Stopper (multiple)
- Parafilm
- Isopropyl Alcohol (IPA) , $(CH_3)_2CHOH$
- Tweezers
- Deionized (DI) water
- Lab-Scale Ultrafiltration Unit

Figure 6: Image of the Lab-Scale Ultrafiltration Unit Disassembled

- Plastic jug with drain tube
- Graduated Cylinders of Various Sizes
- Nitrogen Gas and Tank
- Pressure Gauge
- Spectrophotometer, UV_{254}
- Two Curettes
- Non-Lint Tissue Paper
- Sample Jars (multiple)
- Analytical Scale

- Stopwatch
- Filtering Flask
- Glass Filter Stopper
- Pressure Pump
- 50 mm, 0.45 μ Membrane
- Raw Water Sample (from Pre Water Treatment Facility)
- Total Organic Carbon Analyzer
- 0.1 M Sodium Hydroxide (NaOH)
- Superlite DAX-8 Resin
- Cotton Material
- Methanol (CH_3OH)
- Absorbing Column
- Peristaltic Pump
- Ultrapure Water
- Resin Absorbing Column
- Hydrochloric Acid (HCl)
- pH Meter
- Known solution of Sodium 3-bromopropanesulfonate
- 10 mM of Potassium Chloride (KCl)
- Known mM Solution of Tris (hydroxmethyl) amino-methane (Tris), $C_4H_{11}NO_3$
- Streaming Potential Filtration Equipment
- Polyether Sulfone (PES) Filter
- Electrodes
- Multimeter

3.2 Nomenclature

A = Membrane Area (m^2)

C_f = Feed Concentration (Conc.) (mg/L)

C_P = Permeate Conc. (mg/L)

C_t = Raw Water Conc. at Time t (mg/L)

C_{t+1} = Raw Water Conc. at Time t+1 (mg/L)

ΔE = Streaming Potential (volts)

J = Flux ($m^3/(m^2*s)$ or m/s)

m = mass of the water sample (g)

ΔP = Trans-membrane Pressure (Pa)

Q_f = Flowrate of water (m^3/s)

R = Resistance (m^{-1})

Ät = Change in Time (min)

V = Permeate Volume (cm^3)

ε_o = Permittivity of vacuum

ε_r = Dialect Constant of Membrane

ζ = Zeta Potential

κ = Conductivity of Water

μ = dynamic viscosity (Pa*s)

ñ = Density (g/cm^3)

3.3 Theoretical Approach

In the experiment the area, A, of the UF membrane will be given and constant while the flow rate of the water through the membrane, Q_f, is measure. These values combined will give the flux rate, J, of the system.

$$J = {}^{Q}/_{A} \qquad (1)$$

The volumetric flowrate is not measured but can be calculated using the viscosity, time, and weight of the samples collect. The new equation for the flux becomes:

$$J = {}^{m}/_{(\Delta t \times \rho \times A)} \qquad (2)$$

The density of the water used in this equation is assumed to be 1.0 g/cm^3 and any variations due to temperature or changing concentrations of organic matter are negligible. Therefore, since the area of the membrane is also constant, the change in flux is dependent on the change in mass over time.

Another value that will be calculated will be the resistance of the membrane, R. This can be found by measuring the concentration of NOM on both sides of the membrane as seen in Equation 3.

$$R = {(C_f - C_P)}/{C_f} = 1 - {C_P}/{C_f} \quad (3)$$

In order to find C_f we can either measure the concentration directly or integrate. To measure the concentration directly, either the absorbance or the total organic carbon can be used. However, UV can be adversely affected by turbidity at times, which may throw off results. The following series of equations shows the integration process and final equation required behind the theory of the rejection rate.

$$V \int_{C_t}^{C_{t+1}} \delta C_f = (C_f - C_P)\, Q_f \int_{t_t}^{t_{t+1}} \delta t \quad (4)$$

$$V\,(C_{t+1} - C_t) = (C_f - C_P)\, Q_f \times \Delta t \quad (5)$$

Where C_t is the concentration of the feed at the start of the time interval and C_{t+1} is the concentration of the feed at the end of the time interval.

$$V\,(C_{t+1} - C_t) = (C_t - C_P)\,\frac{\Delta t \times m}{\rho \times \Delta t} \quad (6)$$

$$C_{t+1} = (C_t - C_P)\,\frac{m}{\rho \times V} + C_t \quad (7)$$

Additionally the membrane hydraulic permeability, Lp, will be measured between each step of the preparation and cleaning process of the experiment to determine how the various steps impair the effectiveness of the membrane.

$$L_P = {\mu \times J}/{\Delta P} \quad (8)$$

The flux filtration rate for this equation will be with flux of un-tampered deionized water. This will ensure that the measurement will only be that of the effects of the filter and not of the water itself.

Every solid object in solution has a surface charge and so a distribution of ions near the surface occurs as shown previously from Figure 4. Passing a liquid over the surface disrupts this distribution and creates a potential difference known as the streaming potential. The Streaming potential as well as the permittivity of vacuum, dialect constant of the membrane, and the conductivity of water should all remain constant throughout our calculations since all four of those values depend on both the membrane and water's physical characteristics and those will remain constant throughout the experiment. Once all of those constants are determined, the zeta potential, ζ, can be found.

$$\zeta = (\Delta E / \Delta P) \times (\mu \times \kappa) / (\varepsilon_o \times \varepsilon_r) \quad (9)$$

With all of those variables accounted for, there will be enough data available to have a justifiable comparison for the modified versus non-modified membranes.

3.4 Experimental Approach

3.4.1 Pre Experimental Preparation and L_P Measurement

1. Prepare a new regenerative cellulous (RC) membrane with a diameter of 25 mm and a nominal molecular weight limit (NMWL) of 30,000 (30KD). RC membranes are used because they are common place and are used currently in the water treatment industry [23]. Preparation is done by allowing it to soak in a small sealed glass bottle in isopropyl alcohol (IPA), $(CH_3)_2CHOH$, for at least one hour. This is done to remove any residual harmful chemicals still contained within the membrane from the manufacturing process. To seal the bottle use a ground glass stopper and parafilm. This is how the membrane should be soaked every time. Handle the membrane with tweezers as much as possible to prevent transfer of organic material from the skin onto the membrane and to prevent any unnecessary damage.
2. After the membrane has soaked, rinse with deionized (DI) water.
3. Set up the ultrafiltration system with the membrane inside. Add approximately 250 mL of DI water within the plastic jug attached to it and place a small graduate cylinder to collect the permeate between measurements.

Figure 7: Ultrafiltration System Setup

4. Once everything is attached tightly, the pressure can be turned on by turning the Nitrogen gas tank knob counter clockwise and then adjusting the pressure at the pressure gauge. Pressure is added by twisting the knob clockwise. Set at a high pressure close to but no greater than 1 mega-Pascal (MPa).
5. Allow at least 20 ml of DI water to flow through the membrane to remove any residual IPA from the system.
6. Once the 20 ml has ran through the membrane, set the pressure of the system to approximately 0.02 MPa and wait approximately one minutes for the pressure to stabilize.
7. Weight a sample jar on an analytical scale and record.
8. Once the pressure is stable, place the sample jar under the permeate stream for one minute. Keep an accurate track of the time (with a stopwatch) of the permeate flow collected.
9. Weigh the sample jar with the permeate water.
10. Repeat steps 6 through 9 for the approximate values of the following pressures: 0.04, 0.06, 0.08 and 0.10 MPa at a time interval of 60 seconds each time. The slope of this data will be the L_P of the new membrane. This will be the procedure followed every time the L_P of the filter needs to be measured. The L_P needs to be measured between each process in filtration operation. This includes: the new membrane, after treatment (if applicable), pre-adsorption, after filtration, and after cleaning

3.4.2 Raw Water Preparation

11. Prepare sample raw water. This is done by attaching a flask to a pressure pump and running the amount of raw water needed for the experiments through a 50 mm diameter, 0.45 μm pore size membrane. The amount of raw water needed may vary but a volume of one liter will suffice in most cases.

Figure 8: Raw Water Treatment Process

12. Once the L_P is measured and the raw water treated, disassemble the filtration system and soak the membrane in the treated raw water for around 24 hours.
13. Set the Spectrophotometer at an ultraviolet (UV) setting of 254 and then test the UV of DI water in two separate curettes. Make sure to rinse before use and dry with non-lint tissue paper. Zero the setting to the DI water curette with the lowest measurement and if the other curette has a different value, simply subtract that value from the final results. Assume that that difference is error within the curette and cleaning process of the curette since the ultrapure water samples should have the same UV reading.

3.4.3 Raw Water Measurement

14. Repeat steps 3 through 10. This time the slope of this measurement will be Pre-absorption L_P.
15. Weigh 30 sample jars and record.
16. Add approximately 250 mL of raw water sample into the filtration system jug.
17. Set the pressure to 0.69 MPa. This should be the standard pressure for all non-L_P and non-specified pressure measurements.
18. Use a sample jar is to collect the permeate water for four minutes. Then another jar to measure the next 4 minutes of water.

19. Record the weight of each individual jar plus the sample.
20. Step 18 and 19 are repeated until all 30 jars have been measured, which will be approximately two hours. Save the first 8 sample jars until the end of the run. These will be used to test the initial rejection rate.
21. Use the first sample collected for measuring the absorbance of the initial permeate and use the water that the filter was soaking in for 24 hours for the initial pre-filtration measurement. Use the spectrophotometer to measure the absorbance.
22. Use the remainder 7 initial jars of the sample collected to test the total organic carbon (TOC) using the total organic carbon analyzer.
23. Collect a sample of water at the end of the run and again measure the UV and TOC of the final permeate of the water.
24. Disassemble the filtration system and collect the water within the cylinder section and use that water to test for the absorbance and TOC of the final pre-filtration sample.
25. Rinse the membrane with DI water.
26. Measure the L_P of the membrane after filtration as before.
27. Turn the filter 180 degrees within the filtration system and run the DI water through at a pressure between 0 and 0.02 MPa until water comes out at a steady rate. This is referred to as physical cleaning or backwashing the membrane. It is used to remove any matter build up on the surface of the membrane.
28. Remove the filter from the setup and again rinse with DI water.
29. Allow the membrane to soak in 0.1 M sodium hydroxide (NaOH) for 5 minutes. This part is known as the chemical cleaning of the membrane and is used to attempt to remove some of the buildup that is occurring within the membrane pores.
30. Rinse with DI water and measure the L_P after cleaning.

3.4.4 Hydrophilic Water Preparation and Measurements

31. Soak Superlite DAX-8 Resin in methanol for 24 hours in a sealed glass bottle.
32. Soak some cotton material (enough to fill the bottom of the absorbing column up to 4 cm) in methanol, swirl, and allow it to sit in a sealed container for 24 hours.
33. Attach an absorbing column to a peristaltic pump and run ultrapure water from a beaker through the system for several minutes in order to rinse.

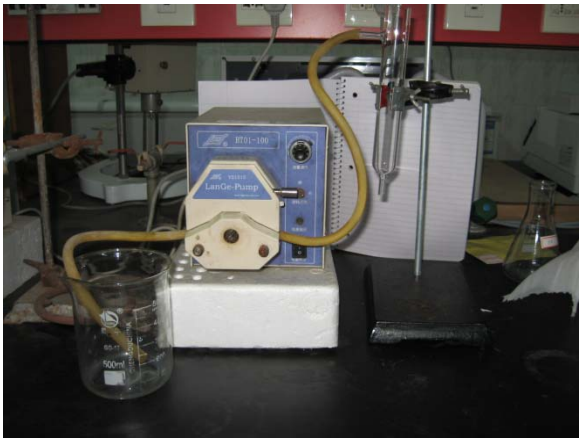

Figure 9: Absorbing Column Setup

34. Retrieve the resin and cotton that has been soaking and dump the methanol in a beaker with water to dilute before sending it down the drain.
35. Thoroughly wash the resin with ultrapure water. Rinse each at least four times. An acceptable amount of resin will be lost during the rinsing process.
36. Removed the cotton that has been soaking in methanol and again dilute and send the methanol down the drain as before.
37. Rinse the cotton with ultrapure water four times and then pack it into the bottom of the absorbing column.
38. Add the resin on top of the cotton material.
39. Ultrapure water should then be pumped again for a few minutes to continue removing any residual methanol.
40. Samples of the product stream from the absorber should be collected and their UV absorbance measured and compared to an un-tampered sample of ultrapure water. Once the two measurements matched the resin and cotton are considered to be clean.
41. Adjust the pH of 250 mL of raw water to below 2 using Hydrochloric acid (HCl). Measure the pH with a pH meter for accurate results.
42. Pumped the adjusted raw water through the absorber column at a rate ranging between 3 to 5 mL/min. Allow a little bit of the sample water to discharge before collecting the rest in order to remove any residual ultrapure water.
43. Once all of the permeate water has been collected, readjusted the pH back to 7.5. This water is considered to be hydrophilic, even though technically there will be residual

traces of transphilic matter within the sample as well. These were considered to be negligible for the purposes of this report.

44. Repeat the Pre Experimental Preparation and L_P Measurement steps for a new membrane.
45. Next, soak the new membrane within the hydrophilic water for 24 hours.
46. Repeat the Raw Water Measurement procedure with the hydrophilic water.

3.4.5 Hydrophobic Water Preparation and Measurements

47. Adjust the pH of approximately 250 mL of ultrapure water to a pH above 12 using the NaOH.
48. Repeat the procedure of the Hydrophilic Water Preparation and Measurement for the now hydrophobic water.

3.4.6 Negatively Charged Membrane Preparation and Measurements

49. Prepare a solution of a known concentration of Sodium 3-bromopropanesulfonate and ultrapure water.
50. Place a RC membrane within the solution and allow it to soak for 48 hours.
51. Mix 10 mM of Potassium Chloride (KCl), and 1 mM of Tris (hydroxmethyl) amino-methane (Tris), $C_4H_{11}NO_3$, to form an electrolyte liquid.
52. Assemble the streaming potential filtration equipment using the treated RC membrane and fill with the electrolyte liquid. It is important that there are absolutely no bubbles within the filtration setup because any air can severely throw off the results.

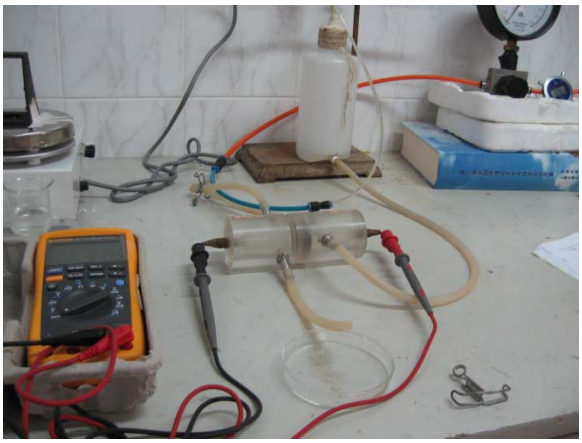

Figure 10: Streaming Potential Filtration Setup

53. Place the two electrodes on either end of the filtration equipment and attach the multimeter to both of the electrodes. Attach the anode to the side where the fluid enters the equipment and then attach the cathode to the permeate end.
54. Set the pressure to 5 kPa and wait for the reading on the multimeter to be stable. This can take up to five minutes at times.
55. Chose four more pressures (10, 15, 20 and 25 kPa) and measure the millivolts (mV) at each of these pressures.
56. The new treated membrane should repeat the same process from the beginning, only now measuring the streaming potential between various steps. These steps include: after treatment, pre-adsorption, after filtration and after cleaning.

4.0 Results and Discussion

This section of the report is broken up into five separate sections that deal with the separate filtration processes and the experimental process as a whole. Each section presents a different set of data that covers the following: the membrane hydraulic permeability, initial flux, ultrafiltration flux, rejection rate, and electric potential of the modified membranes. Furthermore, this section will cover the effectiveness of the measurements and potential errors in the design of the experiment.

The data collected in China was broken up into three parts. There were two trial runs where practical aspects of measuring the different quantities were flushed out and the design was finalized. The first part of the trial run can be seen in Appendix C and is the process design for the non-modified membrane. The second part is for the modified membrane and can be found in Appendix D. For the full set of data, including all calculated numbers and figures as well as sample calculations used for the final set of data for this section, see Appendix B.

4.1 The Membrane Hydraulic Permeability

The membrane hydraulic permeability, L_P, measures the membranes ability to flow ultrapure water through the system over a gradient of pressures. The value itself is the slope of the flux of the ultrapure water versus the pressure. When it is measured through different steps in the filtration process it allows a comparison on how various steps effect how the membrane functions. These steps include the new membrane, after modification, pre-adsorption, after filtration, and after cleaning. The values measured can be found in Table 4 through Table 6.

It is interesting to observe from this data that, at least for the modified membrane, the pattern is similar between all three water type trails. The initial L_P started somewhere between 1,816 and 1,835 and then the value decreased for the steps after modification, pre-adsorption, and after filtration. This trend is to be expected because during all of those processes the membrane is being subjected to contaminated water or a solution of

water. The L_P only increases after cleaning for all three modified membrane cases. The main difference between the modified membrane series is the scale of which the L_P changed. Most notably was the change from beginning to end L_P for hydrophobic compared to that of hydrophilic and raw water. The raw water had an initial L_P of 1,835 and ended with 1,705, which equates to a total change of 131. Additionally, the results for hydrophilic were 92, while the change in the hydrophobic was more than double that of raw water, coming in at 356. This shows that although hydrophobic has a more drastic effect on the membrane the hydrophilic part is the more dominating component in the raw water mixture. This hypothesis is additionally reflected in the graphs from Figure 11 through Figure 13.

Table 4: Raw Water L_P

Raw Water					
Non-Modified Membrane	L_P	ΔL_P	**Modified Membrane**	L_P	ΔL_P
New Membrane	1871.8		New Membrane	1835.2	
---			After Modification	1830.1	*-5.1*
Pre-Adsorption	1742.5	*-129.3*	Pre-Adsorption	1702.1	*-128.0*
After Filtration	1937.2	*194.7*	After Filtration	1680.3	*-21.8*
After Cleaning	1655.8	*-281.4*	After Cleaning	1704.7	*24.4*

Table 5: Hydrophobic Water L_P

HPO Water					
Non-Modified Membrane	L_P	ΔL_P	**Modified Membrane**	L_P	ΔL_P
New Membrane	1906.9		New Membrane	1816.0	
---			After Modification	1596.3	*-219.7*
Pre-Adsorption	1860.0	*-46.9*	Pre-Adsorption	1515.7	*-80.6*
After Filtration	2080.0	*220.0*	After Filtration	1420.2	*-95.5*
After Cleaning	2057.8	*-22.2*	After Cleaning	1460.5	*40.3*

Table 6: Hydrophilic Water L_P

HPI Water					
Non-Modified Membrane	L_P	ΔL_P	**Modified Membrane**	L_P	ΔL_P
New Membrane	1779.7		New Membrane	1821.0	
---			After Modification	1734.9	*-86.1*
Pre-Adsorption	1788.8	*9.1*	Pre-Adsorption	1688.0	*-46.9*
After Filtration	1775.6	*-13.2*	After Filtration	1686.9	*-1.1*
After Cleaning	1788.2	*12.6*	After Cleaning	1728.9	*42.0*

When observing the non-modified membrane, it is discovered that their L_P is more sensitive to changes in the membrane. This can be reflected by example of the initial L_P of the new membranes. The range of values is much greater than was seen in the modified membranes, with a low value from hydrophilic water at 1,780 and a high number from of hydrophobic of 1,907. The range for this set of data therefore equals 127 compared to the 19 of the modified membrane. These results make the L_P harder to follow and harder to compare from the non-modified membrane side. Furthermore, the changes between steps are not consistent for the three different membranes. Therefore, the most logical conclusion that can be made from the data is that a modified membrane provides more stability to the filtration process and the individual steps within it compared to that of a non-modified membrane.

4.2 Initial Flux

The initial flux is a measurement of ultrapure water flowing at the set pressure of 0.69 MPa for one sample worth. It was collected for each step of the membrane process to show the relative flux rates. Data is shown in Table 7 through Table 9.

Table 7: Raw Water Initial Flux

RAW WATER				
Non-Modified Membrane	Time		Flow Rate (g/min)	Initial Flux (10^{-5} m/s)
	min	sec		
New Membrane	3	58	0.8828824	3.589
Pre-Adsorption	4	0	0.864325	3.514
After Filtration	4	0	0.914325	3.717
After Cleaning	4	0	1.00015	4.066
Modified Membrane	Time		Flow Rate (g/min)	Initial Flux (10^{-5} m/s)
	min	sec		
New Membrane	4	0	0.8452	3.436
After Modification	3	58	0.8689412	3.532
Pre-Adsorption	4	1	0.7979253	3.244
After Filtration	4	2	0.794281	3.229
After Cleaning	4	0	0.86055	3.498

Table 8: Hydrophobic Water Initial Flux

HPO WATER				
Non-Modified Membrane	Time		Flow Rate (g/min)	Initial Flux (10^{-5} m/s)
	min	sec		
New Membrane	4	0	0.89185	3.625
Pre-Adsorption	4	1	0.9287303	3.775
After Filtration	4	0	0.888625	3.612
After Cleaning	4	1	0.9767801	3.971
Modified Membrane	Time		Flow Rate (g/min)	Initial Flux (10^{-5} m/s)
	min	sec		
New Membrane	4	0	0.85995	3.496
After Modification	3	58	0.7723109	3.139
Pre-Adsorption	4	1	0.7403402	3.010
After Filtration	4	0	0.674275	2.741
After Cleaning	4	2	0.6994959	2.843

Table 9: Hydrophilic Water Initial Flux

HPI WATER				
Non-Modified Membrane	Time		Flow Rate (g/min)	Initial Flux (10^{-5} m/s)
	min	sec		
New Membrane	4	0	0.8476	3.446
Pre-Adsorption	4	1	0.8514772	3.461
After Filtration	4	0	0.84695	3.443
After Cleaning	4	2	0.8493471	3.453
Modified Membrane	Time		Flow Rate (g/min)	Initial Flux (10^{-5} m/s)
	min	sec		
New Membrane	4	0	0.846625	3.442
After Modification	4	0	0.811475	3.299
Pre-Adsorption	3	59	0.8066611	3.279
After Filtration	4	2	0.8071983	3.281
After Cleaning	4	4	0.798959	3.248

From this we can note the overall change in the flux for the non-modified versus the modified membranes. In the case of hydrophilic and hydrophobic water filtration the modified membranes flux rate decreases slightly from the initial value after cleaning. On the other hand, for all three cases for the non-modified membrane the flux actually increased above the initial value after cleaning. This proves that when the membrane is subjected to modification, it is more susceptible to permanent fouling of the membrane. However, in the case of raw water, the flux once again increased even for the modified

membrane. The difference between the raw water and the HPO and HPI water is that there are other contaminants beyond HPO and HPI, such as transphilic OM that is also in the raw water.

4.3 Ultrafiltration

Although the L_P and the initial flux show the characteristics of the filtration process and can give some general information on how the modified membrane affects these processes versus the non-modified, it does not paint a clear picture of what is going on during filtration and how efficient the process is from start to finish. For that we need to make measurements during the process.

In the ultrafiltration section of the research there is a clear pattern of the blue, uncharged filter having a greater flux than that of the red, charged filter, shown in Figure 10 to Figure 12. This means that the applying the chemical solution to the membrane did not effectively improve the flux of filtration. Instead the flux remained basically unchanged, as in the case of the hydrophilic water, or drastically decreased over time, as in the case of hydrophobic water. The raw water sample, which contained both HPI and HPO content seems to be an average of the two results.

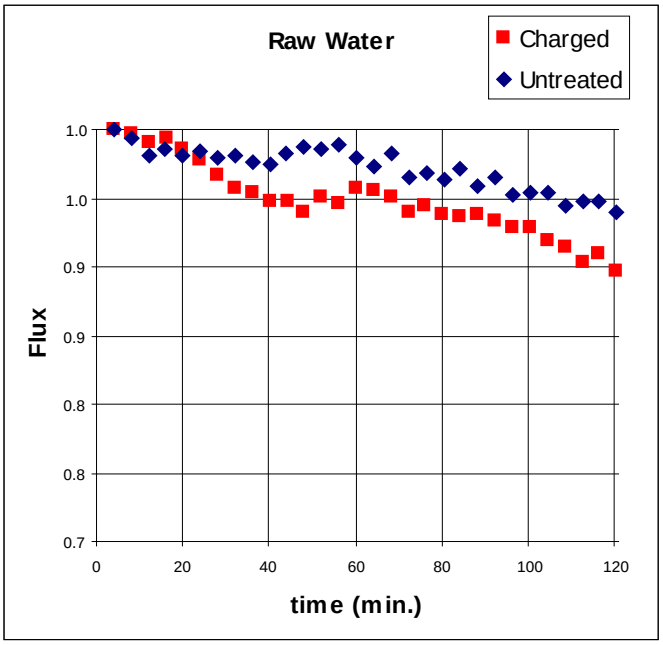

Figure 11: Raw Water Ultrafiltration

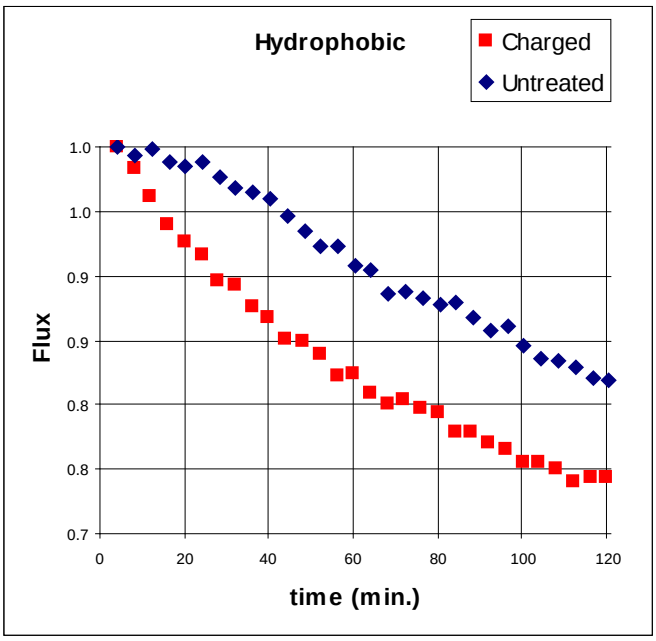

Figure 12: Hydrophobic Water Ultrafiltration

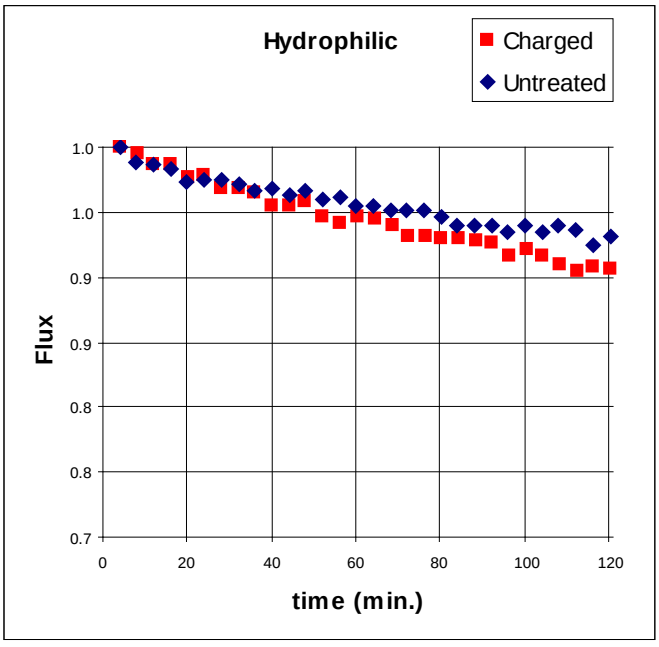

Figure 13: Hydrophilic Water Ultrafiltration

Possible reasons behind the decrease in the flux could be the fact that the charged membrane attracts more particles and filters more than the untreated membrane and therefore, is blocked more easily. Additionally, the chemical additive itself, consisting of

a solution of Sodium 3-bromopropanesulfonate could have effectively clogged the pores of the membrane. To better understand the direct effects of the chemical additive and the flux decline, information on the L_P and the rejection rate are provided in the following sections.

Some errors that occurred during the filtration process were mostly caused by the equipment and design of the system. The pressure was set at a constant level at the beginning of the process but it was near impossible to maintain it throughout the experiment. Part of the reason for this was due to drifting of the needle within the pressure gauge while waiting for it to settle on the actual value. Another issue that arose with the pressure was that as the two hours passed by there was less water was in the tank of the system. As the volume of the water decreased, the pressure also decreased. Although it decreased at a steady rate and the final pressure was recorded for each trial and all trials had similar results, there is no doubt that this change played an effect on the data collected. This is evident in the L_P values that reflect how integral the pressure plays apart in the accuracy of the filtration system.

4.4 Rejection Rate

The rejection rate for the membranes was measured by both UV-254 and by a Total Organic Carbon Analyzer; however the analyzer turned out to be a finicky machine that produced inconsistent data. For that reason, it was discarded and only the UV values will be discussed in this section. See the appendix for the Total Organic Carbon Analyzer data. According to MacCraith, et. al., “UV-254 absorbance is measured by shining an ultraviolet light through a small sample of water and measuring how much of the light is absorbed at a wavelength of 254 nm by material in the water. It can sometimes be adversely affected by turbidity; however it is a simple and effective method for measuring the natural organic matter from the system” [21]. Since the filter was treating water for a drinking water treatment facility versus a waste water facility the amount of turbidity is much less in comparison.

The actual measurement of absorbance is based on a zeroed ultrapure water measurement. The rejection rate is then calculated by dividing the change in concentration by the final concentration. This means the smaller the rejection rate, the

better the filtration is working. For every filter except for the modified hydrophobic membrane the rejection rate increased from the start of filtration to the end of filtration as shown in Table 10 through Table 12. One possible reason for the anomaly seen in the modified hydrophobic membrane could be due to the accuracy of the spectrometer and the number of significant digits it provided. The filters for hydrophilic water were particularly effective, producing an absorbance to only the thousandth decimal place, while the machine can only effectively provide data to the accuracy of ±0.0005 assuming that there is no error in the curettes or contaminates in the ultrapure water.

From these measurements it is observed that although less water is traveling through the modified membrane compared to the non-modified one, as shown in section 4.3 Ultrafiltration, the amount of contaminants has indeed decreased. This is proved by the fact that the rejection rate for the modified membrane in all three cases is less than the rejection rate for the non-modified membrane at both the start of filtration and the end of filtration. Less contaminants means clearer, cleaner water.

Table 10: Raw Water Rejection Rate

Raw Water				
Modified Membrane	Start of Filtration		End of Filtration	
	Prefiltration	Permeate	Prefiltration	Permeate
Absorbance	0.251	0.032	1.389	0.054
Rejection (Abs.)	0.8725		0.9611	
Non-Modified Membrane	Start of Filtration		End of Filtration	
	Prefiltration	Permeate	Prefiltration	Permeate
Absorbance	0.250	0.018	1.358	0.033
Rejection (Abs.)	0.9280		0.9757	

Table 11: Hydrophobic Water Rejection Rate

HPO				
Modified Membrane	Start of Filtration		End of Filtration	
	Prefiltration	Permeate	Prefiltration	Permeate
Absorbance	0.122	0.097	0.267	0.101
Rejection (Abs.)	0.2049		0.6217	
Non-Modified Membrane	Start of Filtration		End of Filtration	
	Prefiltration	Permeate	Prefiltration	Permeate
Absorbance	0.122	0.071	0.377	0.075
Rejection (Abs.)	0.4180		0.8011	

Table 12: Hydrophilic Water Rejection Rate

HPI				
Modified Membrane	Start of Filtration		End of Filtration	
	Prefiltration	Permeate	Prefiltration	Permeate
Absorbance	0.008	0.006	0.008	0.007
Rejection (Abs.)	0.2500		0.1250	
Non-Modified Membrane	Start of Filtration		End of Filtration	
	Prefiltration	Permeate	Prefiltration	Permeate
Absorbance	0.009	0.005	0.019	0.007
Rejection (Abs.)	0.4444		0.6316	

4.5 Electric Potential

The final measurement made was the electric potential of the modified membranes. Originally the experiment was set up to measure the potential at every step of the filtration process, much like in the measurement of the L_P and the initial flux, however, during the trial run it was observed that the streaming potential remained relatively constant and unchanged throughout the process so it was unnecessary. Additionally, the membranes became weaker from constant subjection to chemical exposure, from the bromo-solution to the tris-solution. Once the membrane is weakened it is easy to tear or damage. Once that happens, the experiment has to run from the beginning, so it was safer to measure the potential once and at the end of the experiment. Though the fragility of the membrane when modified would be something to consider in future experiments and larger scale testing units to make sure it isn't a serious issue.

The values for the streaming potential for the three membranes are shown in Table 13. It can be seen in the appendix that the values for the streaming potential are fairly accurate, as displayed by the r squared values all existing above 0.999. However, the voltage meter used for measuring the voltage drop across the filter was erratic and often gave strange values. The streaming potential was measured an average of six time for each membrane and typically the median value with the highest r squared value was selected as the zeta value.

Table 13: Modified Membranes Streaming Potential

Streaming Potential	Zeta (mV)
Raw	-5.59
HPO	-7.52
HPI	-4.67

This report did not take into account the range of different zeta values, just the fact that the membrane was negative. Valuable future research could be done evaluating the effectiveness of the membrane at several difference charges to see if the magnitude of the charge plays an integral role. The difficulty with this is that the charge of the membrane is not a value that can be easily measured or controlled. For example, in this experiment, the conditions were the same for every negatively charged membrane, from the concentration of the bromo-solution to the relative adsorption time, and yet the zeta had a range of ± 1.5 mV. As for now it was assumed that any drastic variations between charges do not have a drastic effect on the data collected. The actual values of the charged membranes for this report can be seen above in Table 13.

5.0 Scale-Up Design and Cost Analysis

Now that the ultrafiltration system has been studied on a lab scale process, it is time to design a full scale system to understand the feasibility of implementing this technology.

Before designing a water treatment facility, the size of the facility and the amount of water to be treated must be considered. This system will be classified as a medium capacity design, which means that it will serve a range of population from 3,301 to 10,000 [13]. An average annual rate of use in gallons per capita per day (gpcd) of 180 is commonly found in the United States with a variance of 150 to 210 gpcd [17]. The system will be designed to take on the maximum capacity which means 10,000 people at a rate of 210 gpcd. This leads to a design with a maximum daily flow of 2,100,000 gallons.

First, a standard water treatment design will be considered. This system will consist of an initial screen, a rapid mix tank, coagulant additives, a flocculation basin, a sedimentation basin, rapid sand filters, disinfection additives, storage, and finally a pump to send it off to distribution. Please see Figure 1 from the beginning of this report for a rough diagram of the design. Additionally, all facts about design size and type for the rest of this section will be provided by *Introduction to Environmental Engineering* [10] unless otherwise specified.

To start the process, assuming the screen cost will be assumed negligible, the first piece of equipment to design will be the rapid mix tank, which will be a vertical shaft mixer. The average rapid mix tank volume does not exceed 8 m^3. The water treated will be the raw water studied in Shanghai. For details about the content within the water see Table 2 from earlier in this report. The rapid mix tank is assumed to have a predominant mechanism of sweep coagulation. This means that if jar tests were done on the amount of coagulant versus turbidity, the level of change would be relatively flat for higher doses, meaning minimal charge reversal. For this type of system, a velocity gradient, G, would range from 600 to 1,000 s^{-1}. The velocity gradient is a standard value used for designing the size of a system and can also be defined by the equation below,

$$G = \sqrt{P/\mu V} \quad (10)$$

Where P is the power input in watts, V is the volume of the tank in m^3, and μ is the dynamic viscosity of water in Pa·s. A value of 800 s^{-1} for G will be chosen as well as a volume of 8 m^3. The mean annual temperature in Shanghai is 15.5 °C [28]. The temperature of the water will be assumed at 15 °C for the design of the system. This gives a dynamic viscosity of 1.15×10^{-3} Pa·s [35]. Given these values, the equation above can now be rearranged to solve for the power in watts of the system.

$$P = \mu V G^2 \quad (11)$$

This results in an ideal power equivalent to 5.89 kW. Moreover, for a single impeller rapid mixing tank system, the efficiency is typically equal to 80 percent, giving actual power output of 7.36 kW.

Next, the coagulant dose will be discussed. For simplicity, sufficient alkalinity will be assumed to be present. This is important because alkalinity effects the pH of the system which effects the ability of the coagulant to perform. A pH within the range of 4 to 9 is required for coagulation using sulfate salts, $Fe_2(SO_4)_3 \cdot xH_2O$. Furthermore, it will be assumed that the hardness level of the water will not require adjustment. This assumption is reasonable and will not affect the system greatly because to adjust for hardness simply calls for more chemical additives which would be injected at the same time and location as the coagulant. Since there would be little to no additional equipment, the cost effects are negligible. As for the coagulant dose, it can range anywhere from 2 to 20 mg/L on average. There is no effective method for determining the appropriate dosage without performing a series of jar testing as previously mentioned. For the purposes of this design, a dosage of 10 mg/L will be assumed. This equates to 37.85 mg/gallon or approximately 80 kg of sulfate salt daily for the design system. Compared to the equipment of the system, this chemical dosage is too minor to influence the capital cost.

Next, the flocculation basin needs to be designed. Based on Table 2, it appears that the Shanghai water system is a high turbid water system. For high turbidity the standard range of values for the velocity gradient are from 30 to 80 s^{-1} and the velocity gradient times the detention time ($G \times t_d$), from 36,000 to 96,000. A value of 66,000 for

$G \times t_d$ will be chosen. The standard detention time for the flocculation tank is dependent on the temperature. For a water with the temperature of 20 °C the detention time is typically 20 minutes. This value increases by 7 percent for water at a temperature of 15 °C and by 15 percent for 10 °C. As previously determined, the average annual water temperature for the Shanghai system is 15 °C. This means that the detention time of the flocculation tank will be equal to 21.4 minutes. Given this time and the assumed 66,000 value, the velocity gradient will be equal to 51.4 s^{-1} for the system. This value falls within the 30 to 80 range, so the tank will be operating under normal conditions. Given this information, the volume of the tank can be calculated.

$$V = Q \times t_d \quad (12)$$

The volumetric flow of the water through the system (Q) is 2,100,000 gallons per day and the detention time of the tank is 21.4 minutes. This gives a volume of approximately 120 m^3. The power output of the tank can again be solved by equation discussed earlier. The ideal power for the flocculation basin is 365 Watts while the actual power, assuming 80 percent efficiency, is 456 watts.

Next is the design for the sedimentation tank. This system calls for a type II sedimentation tank due to the coagulation design. The detention time of these type of tanks ranges from 2 to 8 hours. A detention time of 5 hours will be chosen for this system. This gives a volume of 1660 m^3.

A rapid sand filter system is to be designed to follow after the sedimentation tank. This type of filtration system commonly has a loading rate of 120 $m^3/d \cdot m^2$. With this loading rate, the rapid sand filter cross sectional area can be calculated. It comes out to a value of 66.2 m^2. Generally, a depth of 1.8 to 3 meters above the sand is required for a buffer zone while the sand depth ranges between 0.5 and 0.75 meters. A total depth of 3 meters will cover an approximate average of both of these requirements. This gives the tank for the sand filtration a volume of nearly 200 m^3. Additionally, it is important to note that a minimum of at least two sand filters is required to ensure redundancy.

The last step in the process is disinfection. For this design, the most economical solution, chlorine disinfection, will be chosen. The appropriate dose of chlorine typically ranges between 1 to 3 mg/L and a value of 2 mg/L or 4.2 kg /day will be assumed.

Finally, to end the process, a storage tank and a pump should be added on before the water is sent through the distribution pipes. The storage tank will be designed to hold half a day's worth of water generation which is about 4,000 m^3 and the pump must be able to handle a large range of discharge rates.

Now that all of the relative sizes have been determined they can be entered into a cost analysis program called CAPCOST [33]. From this the results in Table 14 below were generated.

Table 14: Cost Analysis for Generic Water Treatment Design

Unit	Details	Total Cost
Rapid Mix Tank	Structure, 8 m^3	$35,000
	Drive, 8 kW	$46,500
Flocculation	Structure, 120 m^3	$35,000
	Drive, 0.5 kW	$49,100
Sedimentation	Structure, 1660 m^3	$129,000
Rapid Sand Filter (x2)	Structure, 200 m^3	$110,800
Storage Tank	Structure, 4000 m^3	$217,000
Pump (x2)	Reciprocating	$27,400
	TOTAL COST	**$649,800**

Next, the ultrafiltration membrane water treatment facility can be designed. This system has the opportunity to replace sedimentation, coagulation, and flocculation. The system design will have a screen, rapid sand filter, ultrafiltration system, and then disinfection and storage. All parts were designed in the previous design, except for the ultrafiltration membrane system itself. From a text book, the cost value estimates for ultrafiltration units for different sizes were provided [6]. These values are summarized in Table 15 below.

Table 15: Ultrafiltration Costs Based on Size

Description	HOUSING TYPE			
	1-Long	2-Long	3-Long	4-Long
Total Cost ($)	20,400	19,250	19,450	23,950
Total Flow (gpm)	2,400	1,500	1,200	1,200
Inlet Pressure (psi)	100	100	100	100
Pump Power (hp)	280	175	140	140

The assigned flowrate to the preliminary design for this paper is 2,100,000 gallons per day which equates to approximately 1,460 gallons per minutes. With this assigned flowrate, the ultrafiltration system to be chosen would ideally be of the 2-Long Housing Type shown in Table 15. This generates a total membrane cost of $19,250. On top of that cost there will be the addition of another pump (and backup pump) to the system. The cost of the membrane water treatment facility is presented below in Table 16.

Table 16: Cost Analysis for Membrane Water Treatment Design

Unit	Details	Total Cost
Rapid Sand Filter (x2)	Structure, 200 m^3	$110,800
Ultrafiltration Membrane	Structure	$19,250
Pump (x2)	Reciprocating	$27,400
Storage Tank	Structure, 4000 m^3	$217,000
Pump (x2)	Reciprocating	$27,400
	TOTAL COST	**$401,850**

The new design for this treatment facility that does not include the traditional processes of sedimentation, flocculation, and coagulation suddenly makes ultrafiltration more competitive in the design market. However, these prices are just rough estimates generated by a computer program and hand calculations. A more accurate representation of costs can be seen through various case studies, which will be presented next.

Table 17: Cost Analysis for Generic Water Treatment Design, Case Study

Description	Total Cost/Item	Total Cost ($ per gal/day)
Powder Activated Carbon System	$7,632,141	$0.19
Ballasted Flocculation-Clarification System	$7,152,872	$0.18
Filter System	$6,311,889	$0.16
Finished Water Storage Tanks & High Service Pump Station	$36,542,040	$0.91
Disinfection System & High Service Pump Station	$5,877,834	$0.15
Chemical Supply Systems	$587,783	$0.01
Process Yard Piping	$6,149,118	$0.15
Site Electrical, Controls and Instrumentation	$9,223,678	$0.23
TOTAL	**$79,477,355**	**$1.99**

Two different facilities were observed. Both systems managed to incorporate different costs that were not considered here. Only the cost of the equipment and

installation was considered. All other costs such as maintenance were considered to be relatively the same. The first system is a large scale facility that is designed to treat a flow of 40 million gallons a day [29]. This system is a standard facility design similar to the one summarized in Table 14 of this section. It contains processes such as flocculation, coagulation, sedimentation, and disinfection. Relevant costs are scaled down and normalized to a dollar per gallon per day basis are summarize in Table 17.

The next system was a smaller system that contained a series of ultrafiltration membranes to treat a flow of 20 m^3/hr or 126,800 gallons per day [12]. This system is summarized in Table 18 below.

Table 18: Cost Analysis for Membrane Water Treatment Design, Case Study

Description	Total Cost/Item	Total Cost ($ per gal/day)
UF Modules (40 total, at $1,000 each)	$40,000	$0.32
Membrane Elements (40 total, at $500 each)	$20,000	$0.16
Diaphragm and Parts	$1,700	$0.01
Cartridge Filter	$3,000	$0.02
Pump for the transfer of pretreated water	$5,500	$0.04
Air Compressor	$5,875	$0.05
Tank of Pretreated Water	$4,000	$0.03
Tank for the storage of treated water	$6,700	$0.05
Tank of the concentrate solution	$4,000	$0.03
UF Feed Pump	$3,000	$0.02
Pump for the transfer of concentrate solution	$3,650	$0.03
Cleaning Material	$6,825	$0.05
Pipes and Accessories	$20,850	$0.16
Regulation Apparatus	$15,640	$0.12
Measurement and Control Apparatus	$7,300	$0.06
Electric and Power Installation	$17,720	$0.14
Electric Command Installation	$5,200	$0.04
Transportation of the main materials	$3,130	$0.02
Civil Infrastructure and Engineering	$70,000	$0.55
Spare Parts	$5,210	$0.04
TOTAL	**$249,300**	**$1.97**

The results of the two case studies reveal that the two systems are still competitive in price and if an ultrafiltration system can be designed to be more efficient than processes such as sedimentation, coagulation, and filtration, are not required, then ultrafiltration is a viable design tool.

6.0 Conclusion

The objective of this study was to investigate the effects of NOM hydrophobic and hydrophilic properties and the effects of fouling a modified membrane compared to that of a non-modified one. This was accomplished through the measurement of the membrane's hydraulic permeability, initial flux, rejection rate, and flux during ultrafiltration.

The hydraulic permeability, L_P, and the initial flux were measured to compare how various steps effect membrane functions. Besides showing how the system functions in each step of the process, the results also provide a comparison of stability within the system between the modified membrane and the non-modified membrane. It was discovered there that the L_P is more sensitive to changes in the non-modified membrane and the data was more inconsistent. This means that a modified membrane provides more stability to the filtration process as a whole and also within the individual process steps.

The rejection rate measures the membranes ability to purify the fluid solutions. From these measurements it was observed that the modified membrane removes more constituents than the non-modified one. In fact, the rejection rate for the modified membrane in all three cases is less than the rejection rate for the non-modified membrane at both the start of filtration and the end of filtration. This equates to cleaner water.

Conclusions about the rate of fluid flow through the system can be drawn from the measurements of the flux during ultrafiltration. In fact, the modified membrane did not effectively improve the flux of filtration compared to that of the non-modified membrane in all three cases. Instead the flux either remained basically unchanged, as in the case of hydrophilic water, or the system substantially worsened, as in the case of hydrophobic water. On top of the lab scale data collection, a cost analysis was presented. From this analysis it was determined that as long as an ultrafiltration unit has a reasonable enough efficiency, it can replace such systems as coagulation, flocculation, and sedimentation. This in turn equates to a comparable capital cost to that of a traditional water treatment facility design.

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8.0 Appendix

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8.1 Appendix Part A

The World Health Organization Drinking Water Standards are shown in the following pages, labeled as 488 to 493, and were taken from the 2004 report.

ANNEX 4

Chemical summary tables

Table A4.1 Chemicals excluded from guideline value derivation

Chemical	Reason for exclusion
Amitraz	Degrades rapidly in the environment and is not expected to occur at measurable concentrations in drinking-water supplies
Beryllium	Unlikely to occur in drinking-water
Chlorobenzilate	Unlikely to occur in drinking-water
Chlorothalonil	Unlikely to occur in drinking-water
Cypermethrin	Unlikely to occur in drinking-water
Deltamethrin	Unlikely to occur in drinking-water
Diazinon	Unlikely to occur in drinking-water
Dinoseb	Unlikely to occur in drinking-water
Ethylene thiourea	Unlikely to occur in drinking-water
Fenamiphos	Unlikely to occur in drinking-water
Formothion	Unlikely to occur in drinking-water
Hexachlorocyclohexanes (mixed isomers)	Unlikely to occur in drinking-water
MCPB	Unlikely to occur in drinking-water
Methamidophos	Unlikely to occur in drinking-water
Methomyl	Unlikely to occur in drinking-water
Mirex	Unlikely to occur in drinking-water
Monocrotophos	Has been withdrawn from use in many countries and is unlikely to occur in drinking-water
Oxamyl	Unlikely to occur in drinking-water
Phorate	Unlikely to occur in drinking-water
Propoxur	Unlikely to occur in drinking-water
Pyridate	Not persistent and only rarely found in drinking-water
Quintozene	Unlikely to occur in drinking-water
Toxaphene	Unlikely to occur in drinking-water
Triazophos	Unlikely to occur in drinking-water
Tributyltin oxide	Unlikely to occur in drinking-water
Trichlorfon	Unlikely to occur in drinking-water

Table A4.2 Chemicals for which guideline values have not been established

Chemical	Reason for not establishing a guideline value
Aluminium	Owing to limitations in the animal data as a model for humans and the uncertainty surrounding the human data, a health-based guideline value cannot be derived; however, practicable levels based on optimization of the coagulation process in drinking-water plants using aluminium-based coagulants are derived: 0.1 mg/litre or less in large water treatment facilities, and 0.2 mg/litre or less in small facilities
Ammonia	Occurs in drinking-water at concentrations well below those at which toxic effects may occur
Asbestos	No consistent evidence that ingested asbestos is hazardous to health
Bentazone	Occurs in drinking-water at concentrations well below those at which toxic effects may occur
Bromochloroacetate	Available data inadequate to permit derivation of health-based guideline value
Bromochloroacetonitrile	Available data inadequate to permit derivation of health-based guideline value
Chloral hydrate (trichloroacetaldehyde)	Occurs in drinking-water at concentrations well below those at which toxic effects may occur
Chloride	Not of health concern at levels found in drinking-water[a]
Chlorine dioxide	Guideline value not established because of the rapid breakdown of chlorine dioxide and because the chlorite provisional guideline value is adequately protective for potential toxicity from chlorine dioxide
Chloroacetones	Available data inadequate to permit derivation of health-based guideline values for any of the chloroacetones
Chlorophenol, 2-	Available data inadequate to permit derivation of health-based guideline value
Chloropicrin	Available data inadequate to permit derivation of health-based guideline value
Dialkyltins	Available data inadequate to permit derivation of health-based guideline values for any of the dialkyltins
Dibromoacetate	Available data inadequate to permit derivation of health-based guideline value
Dichloramine	Available data inadequate to permit derivation of health-based guideline value
Dichlorobenzene, 1,3-	Toxicological data are insufficient to permit derivation of health-based guideline value
Dichloroethane, 1,1-	Very limited database on toxicity and carcinogenicity
Dichloroethene, 1,1-	Occurs in drinking-water at concentrations well below those at which toxic effects may occur
Dichlorophenol, 2,4-	Available data inadequate to permit derivation of health-based guideline value
Dichloropropane, 1,3-	Data insufficient to permit derivation of health-based guideline value
Di(2-ethylhexyl)adipate	Occurs in drinking-water at concentrations well below those at which toxic effects may occur
Diquat	Rarely found in drinking-water, but may be used as an aquatic herbicide for the control of free-floating and submerged aquatic weeds in ponds, lakes and irrigation ditches
Endosulfan	Occurs in drinking-water at concentrations well below those at which toxic effects may occur
Fenitrothion	Occurs in drinking-water at concentrations well below those at which toxic effects may occur
Fluoranthene	Occurs in drinking-water at concentrations well below those at which toxic effects may occur
Formaldehyde	Occurs in drinking-water at concentrations well below those at which toxic effects may occur

Glyphosate and AMPA	Occurs in drinking-water at concentrations well below those at which toxic effects may occur
Hardness	Not of health concern at levels found in drinking-water[a]
Heptachlor and heptachlor epoxide	Occurs in drinking-water at concentrations well below those at which toxic effects may occur

continued

Table A4.2 ***Continued***

Chemical	Reason for not establishing a guideline value
Hexachlorobenzene	Occurs in drinking-water at concentrations well below those at which toxic effects may occur
Hydrogen sulfide	Not of health concern at levels found in drinking-water[a]
Inorganic tin	Occurs in drinking-water at concentrations well below those at which toxic effects may occur
Iodine	Available data inadequate to permit derivation of health-based guideline value, and lifetime exposure to iodine through water disinfection is unlikely
Iron	Not of health concern at concentrations normally observed in drinking-water, and taste and appearance of water are affected below the health-based value
Malathion	Occurs in drinking-water at concentrations well below those at which toxic effects may occur
Methyl parathion	Occurs in drinking-water at concentrations well below those at which toxic effects may occur
Methyl *tertiary*-butyl ether (MTBE)	Very limited toxicological database, and any guideline that would be derived would be significantly higher than concentrations at which MTBE would be detected by odour
Monobromoacetate	Available data inadequate to permit derivation of health-based guideline value
Monochlorobenzene	Occurs in drinking-water at concentrations well below those at which toxic effects may occur, and health-based value would far exceed lowest reported taste and odour threshold
MX	Occurs in drinking-water at concentrations well below those at which toxic effects may occur
Parathion	Occurs in drinking-water at concentrations well below those at which toxic effects may occur
Permethrin	Occurs in drinking-water at concentrations well below those at which toxic effects may occur
Petroleum products	Taste and odour will in most cases be detectable at concentrations below those concentrations of concern for health, particularly with short-term exposure
pH	Not of health concern at levels found in drinking-water[b]
Phenylphenol, 2- and its sodium salt	Occurs in drinking-water at concentrations well below those at which toxic effects may occur
Propanil	Readily transformed into metabolites that are more toxic; a guideline value for the parent compound is considered inappropriate, and there are inadequate data to enable the derivation of guideline values for the metabolites
Silver	Available data inadequate to permit derivation of health-based guideline value
Sodium	Not of health concern at levels found in drinking-water[a]
Sulfate	Not of health concern at levels found in drinking-water[a]
Total dissolved solids (TDS)	Not of health concern at levels found in drinking-water[a]
Trichloramine	Available data inadequate to permit derivation of health-based guideline value
Trichloroacetonitrile	Available data inadequate to permit derivation of health-based guideline value
Trichlorobenzenes (total)	Occurs in drinking-water at concentrations well below those at which toxic effects may occur, and health-based value would exceed lowest reported odour threshold
Trichloroethane, 1,1,1-	Occurs in drinking-water at concentrations well below those at which toxic effects may occur

Zinc	Not of health concern at concentrations normally observed in drinking-water[a]

[a] May affect acceptability of drinking-water (see chapter 10).
[b] An important operational water quality parameter.

Table A4.3 Guideline values for chemicals that are of health significance in drinking-water

Chemical	Guideline value[a] (mg/litre)	Remarks
Acrylamide	0.0005[b]	
Alachlor	0.02[b]	
Aldicarb	0.01	Applies to aldicarb sulfoxide and aldicarb sulfone
Aldrin and dieldrin	0.00003	For combined aldrin plus dieldrin
Antimony	0.02	
Arsenic	0.01 (P)	
Atrazine	0.002	
Barium	0.7	
Benzene	0.01[b]	
Benzo[*a*]pyrene	0.0007[b]	
Boron	0.5 (T)	
Bromate	0.01[b] (A, T)	
Bromodichloromethane	0.06[b]	
Bromoform	0.1	
Cadmium	0.003	
Carbofuran	0.007	
Carbon tetrachloride	0.004	
Chlorate	0.7 (D)	
Chlordane	0.0002	
Chlorine	5 (C)	For effective disinfection, there should be a residual concentration of free chlorine of ≥0.5 mg/litre after at least 30 min contact time at pH <8.0
Chlorite	0.7 (D)	
Chloroform	0.3	
Chlorotoluron	0.03	
Chlorpyrifos	0.03	
Chromium	0.05 (P)	For total chromium
Copper	2	Staining of laundry and sanitary ware may occur below guideline value
Cyanazine	0.0006	
Cyanide	0.07	
Cyanogen chloride	0.07	For cyanide as total cyanogenic compounds
2,4-D (2,4-dichlorophenoxyacetic acid)	0.03	Applies to free acid
2,4-DB	0.09	
DDT and metabolites	0.001	
Di(2-ethylhexyl)phthalate	0.008	
Dibromoacetonitrile	0.07	
Dibromochloromethane	0.1	
Dibromo-3-chloropropane, 1,2-	0.001[b]	
Dibromoethane, 1,2-	0.0004[b] (P)	
Dichloroacetate	0.05[b] (T, D)	
Dichloroacetonitrile	0.02 (P)	
Dichlorobenzene, 1,2-	1 (C)	

continued

Table A4.3 *Continued*

Chemical	Guideline value (mg/litre)	Remarks
Dichlorobenzene, 1,4-	0.3 (C)	
Dichloroethane, 1,2-	0.03[b]	
Dichloroethene, 1,2-	0.05	
Dichloromethane	0.02	
1,2-Dichloropropane (1,2-DCP)	0.04 (P)	
1,3-Dichloropropene	0.02[b]	
Dichlorprop	0.1	
Dimethoate	0.006	
Dioxane, 1,4-	0.05[b]	
Edetic acid (EDTA)	0.6	Applies to the free acid
Endrin	0.0006	
Epichlorohydrin	0.0004 (P)	
Ethylbenzene	0.3 (C)	
Fenoprop	0.009	
Fluoride	1.5	Volume of water consumed and intake from other sources should be considered when setting national standards
Hexachlorobutadiene	0.0006	
Isoproturon	0.009	
Lead	0.01	
Lindane	0.002	
Manganese	0.4 (C)	
MCPA	0.002	
Mecoprop	0.01	
Mercury	0.006	For inorganic mercury
Methoxychlor	0.02	
Metolachlor	0.01	
Microcystin-LR	0.001 (P)	For total microcystin-LR (free plus cell-bound)
Molinate	0.006	
Molybdenum	0.07	
Monochloramine	3	
Monochloroacetate	0.02	
Nickel	0.07	
Nitrate (as NO_3^-)	50	Short-term exposure
Nitrilotriacetic acid (NTA)	0.2	
Nitrite (as NO_2^-)	3	Short-term exposure
	0.2 (P)	Long-term exposure
Pendimethalin	0.02	
Pentachlorophenol	0.009[b] (P)	
Permethrin	0.3	Only when used as a larvicide for public health purposes
Pyriproxyfen	0.3	
Selenium	0.01	
Simazine	0.002	
Styrene	0.02 (C)	
2,4,5-T	0.009	
Terbuthylazine	0.007	
Tetrachloroethene	0.04	
Toluene	0.7 (C)	

Table A4.3 *Continued*

Chemical	Guideline value (mg/litre)	Remarks
Trichloroacetate	0.2	
Trichloroethene	0.02 (P)	
Trichlorophenol, 2,4,6-	0.2[b] (C)	
Trifluralin	0.02	
Trihalomethanes		The sum of the ratio of the concentration of each to its respective guideline value should not exceed 1
Uranium	0.015 (P,T)	Only chemical aspects of uranium addressed
Vinyl chloride	0.0003[b]	
Xylenes	0.5 (C)	

[a] P = provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited; T = provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.; A = provisional guideline value because calculated guideline value is below the achievable quantification level; D = provisional guideline value because disinfection is likely to result in the guideline value being exceeded; C = concentrations of the substance at or below the health-based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

[b] For substances that are considered to be carcinogenic, the guideline value is the concentration in drinking-water associated with an upper-bound excess lifetime cancer risk of 10^{-5} (one additional cancer per 100 000 of the population ingesting drinking-water containing the substance at the guideline value for 70 years). Concentrations associated with upper-bound estimated excess lifetime cancer risks of 10^{-4} and 10^{-6} can be calculated by multiplying and dividing, respectively, the guideline value by 10.

8.2 Appendix Part B

Report data used for the experiment can be found in this section and consist of 23 pages broken up in the following way:

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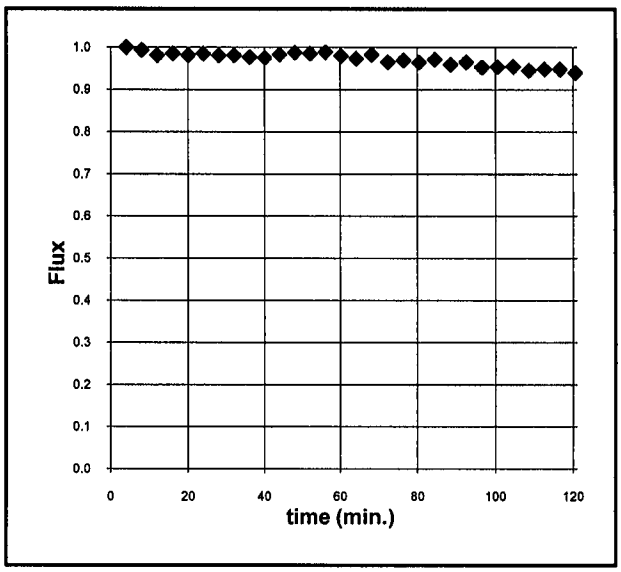
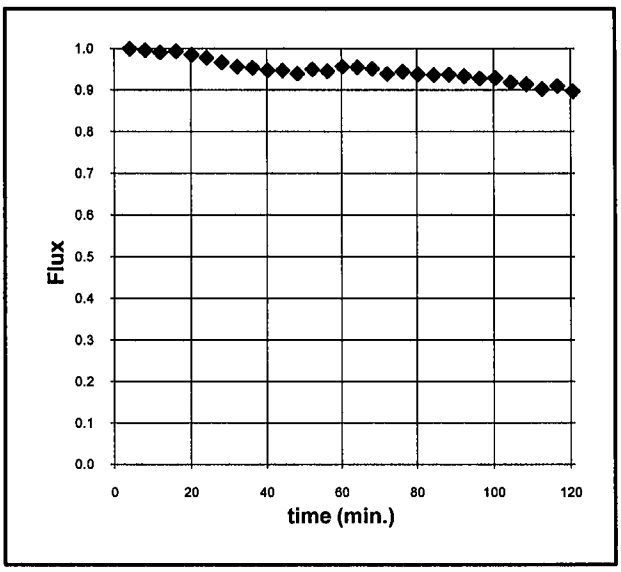
Raw

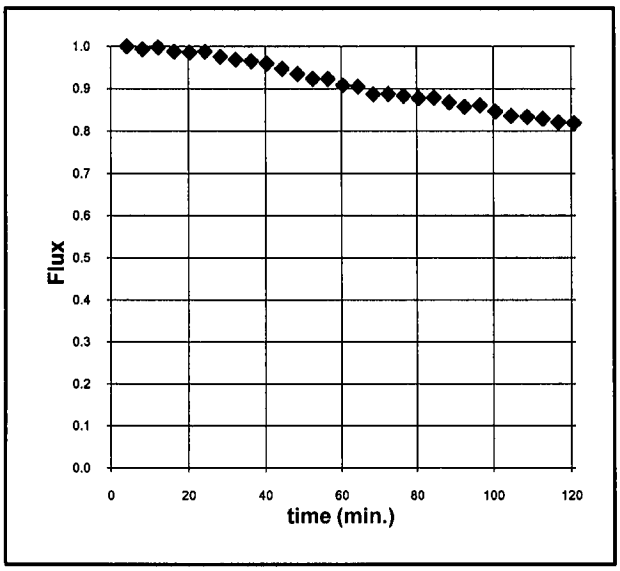
Sample Number	Flask (g)	Flask + Sample (g)	Sample (g)	Time		Time (min)		Flowrate (g/min)	Flux (10^{-5} m/s)	J/J_O
				Min	Sec	Total	Diff.			
1	18.3197	21.5593	3.2396	4	3	4.05	4.05	0.7999	3.252	1.000
2	17.7618	20.9139	3.1521	8	1	8.02	3.97	0.7946	3.230	0.993
3	18.0103	21.1626	3.1523	12	2	12.03	4.02	0.7848	3.190	0.981
4	17.4681	20.6201	3.1520	16	2	16.03	4.00	0.7880	3.203	0.985
5	17.5792	20.7305	3.1513	20	3	20.05	4.02	0.7846	3.189	0.981
6	17.8420	20.9928	3.1508	24	3	24.05	4.00	0.7877	3.202	0.985
7	18.0873	21.2356	3.1483	28	4	28.07	4.02	0.7838	3.186	0.980
8	17.9082	21.0738	3.1656	32	6	32.10	4.03	0.7849	3.190	0.981
9	18.3839	21.5088	3.1249	36	6	36.10	4.00	0.7812	3.176	0.977
10	17.9696	21.0889	3.1193	40	6	40.10	4.00	0.7798	3.170	0.975
11	18.0197	21.1492	3.1295	44	5	44.08	3.98	0.7856	3.194	0.982
12	17.7073	20.8919	3.1846	48	7	48.12	4.03	0.7896	3.210	0.987
13	17.9125	21.0515	3.1390	52	6	52.10	3.98	0.7880	3.203	0.985
14	17.9714	21.2006	3.2292	56	11	56.18	4.08	0.7908	3.215	0.989
15	17.4755	20.6609	3.1854	60	15	60.25	4.07	0.7833	3.184	0.979
16	18.0291	21.1311	3.1020	64	14	64.23	3.98	0.7787	3.166	0.973
17	18.4082	21.5768	3.1686	68	16	68.27	4.03	0.7856	3.194	0.982
18	18.1030	21.2938	3.1908	72	24	72.40	4.13	0.7720	3.138	0.965
19	17.7776	20.8913	3.1137	76	25	76.42	4.02	0.7752	3.151	0.969
20	18.2946	21.4304	3.1358	80	29	80.48	4.07	0.7711	3.135	0.964
21	18.3197	21.4136	3.0939	84	28	84.47	3.98	0.7767	3.157	0.971
22	17.8481	20.9429	3.0948	88	30	88.50	4.03	0.7673	3.119	0.959
23	18.0194	21.1196	3.1002	92	31	92.52	4.02	0.7718	3.138	0.965
24	17.7674	20.8295	3.0621	96	32	96.53	4.02	0.7623	3.099	0.953
25	18.0001	21.0633	3.0632	100	33	100.55	4.02	0.7626	3.100	0.953
26	18.1811	21.2466	3.0655	104	34	104.57	4.02	0.7632	3.102	0.954
27	17.9415	20.9656	3.0241	108	34	108.57	4.00	0.7560	3.073	0.945
28	17.6492	20.6962	3.0470	112	35	112.58	4.02	0.7586	3.084	0.948
29	18.2546	21.2882	3.0336	116	35	116.58	4.00	0.7584	3.083	0.948
30	18.2149	21.2214	3.0065	120	35	120.58	4.00	0.7516	3.055	0.940



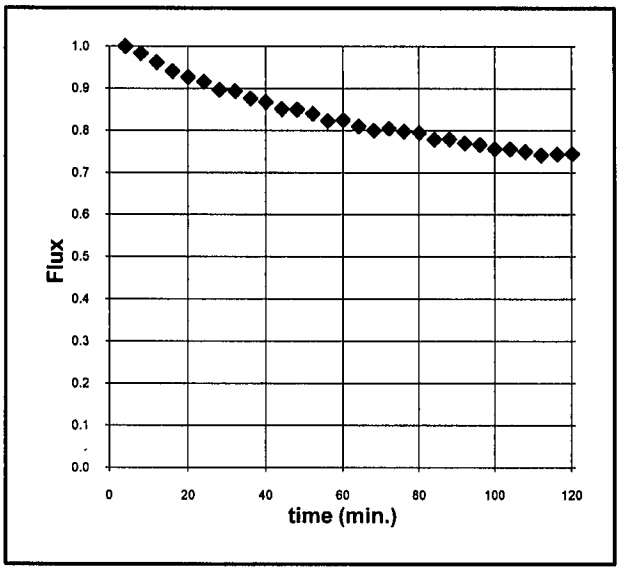
Sample Number	Flask (g)	Flask + Sample (g)	Sample (g)	Time		Time (min)		Flowrate (g/min)	Flux (10^{-5} m/s)	J/J_O
				Min	Sec	Total	Diff.			
1	18.3206	21.5188	3.1982	4	2	4.03	4.03	0.7929	3.223	1.000
2	17.7622	20.9617	3.1995	8	5	8.08	4.05	0.7900	3.211	0.996
3	18.0118	21.1156	3.1038	12	2	12.03	3.95	0.7858	3.194	0.991
4	17.4692	20.6613	3.1921	16	5	16.08	4.05	0.7882	3.204	0.994
5	17.5804	20.7321	3.1517	20	7	20.12	4.03	0.7814	3.176	0.986
6	17.8435	20.9452	3.1017	24	7	24.12	4.00	0.7754	3.152	0.978
7	18.0881	21.1422	3.0541	28	6	28.10	3.98	0.7667	3.117	0.967
8	17.9088	21.0060	3.0972	32	11	32.18	4.08	0.7585	3.083	0.957
9	18.3852	21.3982	3.0130	36	10	36.17	3.98	0.7564	3.075	0.954
10	17.9689	20.9875	3.0186	40	11	40.18	4.02	0.7515	3.055	0.948
11	18.0196	21.0370	3.0174	44	12	44.20	4.02	0.7512	3.054	0.947
12	17.7072	20.6628	2.9556	48	10	48.17	3.97	0.7451	3.029	0.940
13	17.9124	20.9380	3.0256	52	11	52.18	4.02	0.7533	3.062	0.950
14	17.9715	20.9835	3.0120	56	12	56.20	4.02	0.7499	3.048	0.946
15	17.4753	20.5463	3.0710	60	15	60.25	4.05	0.7583	3.082	0.956
16	18.0295	21.0466	3.0171	64	14	64.23	3.98	0.7574	3.079	0.955
17	18.4086	21.4264	3.0178	68	14	68.23	4.00	0.7545	3.067	0.952
18	18.1028	21.0937	2.9909	72	15	72.25	4.02	0.7446	3.027	0.939
19	17.7779	20.7989	3.0210	76	17	76.28	4.03	0.7490	3.045	0.945
20	18.2950	21.2956	3.0006	80	19	80.32	4.03	0.7440	3.024	0.938
21	18.3206	21.3892	3.0686	84	27	84.45	4.13	0.7424	3.018	0.936
22	17.8487	20.8215	2.9728	88	27	88.45	4.00	0.7432	3.021	0.937
23	18.0192	20.9935	2.9743	92	28	92.47	4.02	0.7405	3.010	0.934
24	17.7663	20.6844	2.9181	96	26	96.43	3.97	0.7357	2.990	0.928
25	18.0005	20.9723	2.9718	100	28	100.47	4.03	0.7368	2.995	0.929
26	18.1816	21.1076	2.9260	104	29	104.48	4.02	0.7285	2.961	0.919
27	17.9423	20.8661	2.9238	108	31	108.52	4.03	0.7249	2.947	0.914
28	17.6497	20.5731	2.9234	112	36	112.60	4.08	0.7159	2.910	0.903
29	18.2555	21.128	2.8725	116	35	116.58	3.98	0.7211	2.931	0.910
30	18.2162	21.0733	2.8571	120	36	120.60	4.02	0.7113	2.892	0.897



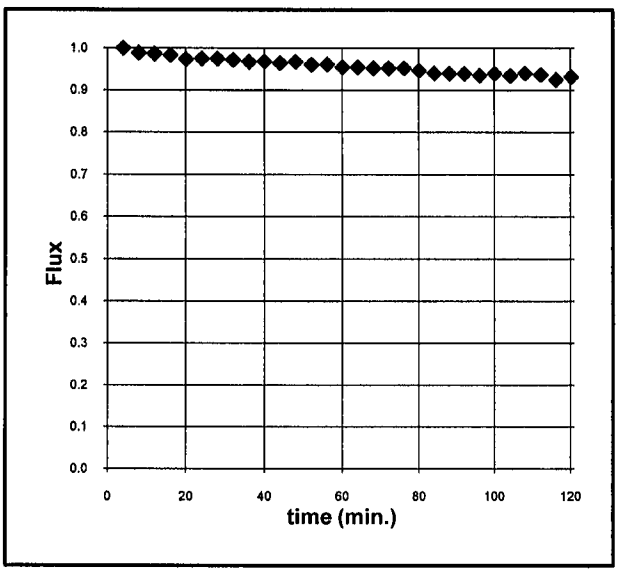
Sample Number	Flask (g)	Flask + Sample (g)	Sample (g)	Time		Time (min)		Flowrate (g/min)	Flux (10^{-5} m/s)	J/J_O
				Min	Sec	Total	Diff.			
1	18.3198	22.1784	3.8586	4	8	4.13	4.13	0.9335	3.795	1.000
2	17.7593	21.5288	3.7695	8	12	8.20	4.07	0.9269	3.768	0.993
3	18.0077	21.7332	3.7255	12	12	12.20	4.00	0.9314	3.786	0.998
4	17.4654	21.3232	3.8578	16	23	16.38	4.18	0.9222	3.749	0.988
5	17.5768	21.1645	3.5877	20	17	20.28	3.90	0.9199	3.740	0.985
6	17.8396	21.5276	3.6880	24	17	24.28	4.00	0.9220	3.748	0.988
7	18.0837	21.7278	3.6441	28	17	28.28	4.00	0.9110	3.703	0.976
8	17.9048	21.4915	3.5867	32	15	32.25	3.97	0.9042	3.676	0.969
9	18.3810	22.0287	3.6477	36	18	36.30	4.05	0.9007	3.661	0.965
10	17.9655	21.5640	3.5985	40	19	40.32	4.02	0.8959	3.642	0.960
11	18.0156	21.5670	3.5514	44	20	44.33	4.02	0.8842	3.594	0.947
12	17.7035	21.2087	3.5052	48	21	48.35	4.02	0.8727	3.547	0.935
13	17.9080	21.3989	3.4909	52	24	52.40	4.05	0.8620	3.504	0.923
14	17.9671	21.4285	3.4614	56	25	56.42	4.02	0.8618	3.503	0.923
15	17.4713	20.8347	3.3634	60	23	60.38	3.97	0.8479	3.447	0.908
16	18.0254	21.3908	3.3654	64	22	64.37	3.98	0.8449	3.434	0.905
17	18.4043	21.7565	3.3522	68	25	68.42	4.05	0.8277	3.365	0.887
18	18.0991	21.4265	3.3274	72	26	72.43	4.02	0.8284	3.367	0.887
19	17.7740	21.1402	3.3662	76	31	76.52	4.08	0.8244	3.351	0.883
20	18.2910	21.5001	3.2091	80	26	80.43	3.92	0.8193	3.331	0.878
21	18.3159	21.6128	3.2969	84	27	84.45	4.02	0.8208	3.337	0.879
22	17.8443	21.1265	3.2822	88	30	88.50	4.05	0.8104	3.294	0.868
23	18.0198	21.2088	3.1890	92	29	92.48	3.98	0.8006	3.254	0.858
24	18.0005	21.2554	3.2549	96	32	96.53	4.05	0.8037	3.267	0.861
25	17.7677	20.9288	3.1611	100	32	100.53	4.00	0.7903	3.213	0.847
26	18.1815	21.3164	3.1349	104	33	104.55	4.02	0.7805	3.173	0.836
27	17.9421	21.1458	3.2037	108	40	108.67	4.12	0.7782	3.164	0.834
28	17.6500	20.8102	3.1602	112	45	112.75	4.08	0.7739	3.146	0.829
29	18.2556	21.2578	3.0022	116	40	116.67	3.92	0.7665	3.116	0.821
30	18.2158	21.3255	3.1097	120	44	120.73	4.07	0.7647	3.108	0.819



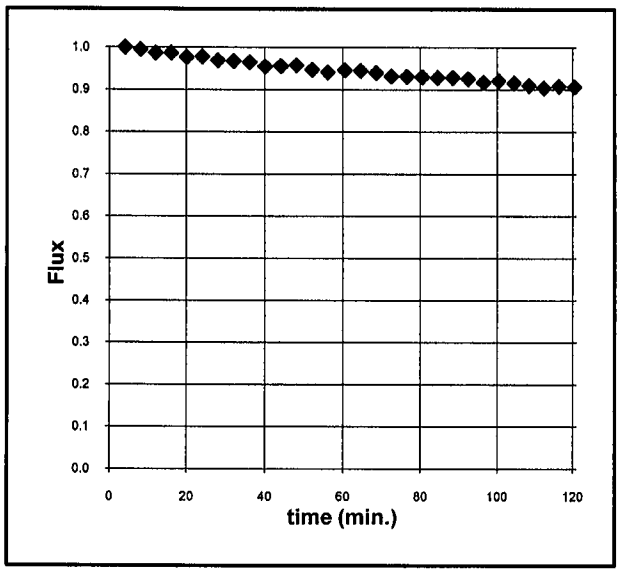
Sample Number	Flask (g)	Flask + Sample (g)	Sample (g)	Time		Time (min)		Flowrate (g/min)	Flux (10^{-5} m/s)	J/J_O
				Min	Sec	Total	Diff.			
1	18.3236	21.2742	2.9506	4	3	4.05	4.05	0.7285	2.962	1.000
2	17.7615	20.6150	2.8535	8	2	8.03	3.98	0.7164	2.912	0.983
3	18.0128	20.8154	2.8026	12	2	12.03	4.00	0.7007	2.848	0.962
4	17.4714	20.2239	2.7525	16	3	16.05	4.02	0.6853	2.786	0.940
5	17.5817	20.2826	2.7009	20	3	20.05	4.00	0.6752	2.745	0.927
6	17.8469	20.5489	2.7020	24	6	24.10	4.05	0.6672	2.712	0.916
7	18.0987	20.6899	2.5912	28	4	28.07	3.97	0.6532	2.655	0.897
8	17.8889	20.5367	2.6478	32	8	32.13	4.07	0.6511	2.647	0.894
9	18.3869	20.9297	2.5428	36	7	36.12	3.98	0.6384	2.595	0.876
10	17.9685	20.4540	2.4855	40	3	40.05	3.93	0.6319	2.569	0.867
11	18.0252	20.5663	2.5411	44	9	44.15	4.10	0.6198	2.519	0.851
12	17.7102	20.1451	2.4349	48	5	48.08	3.93	0.6190	2.516	0.850
13	17.9189	20.4071	2.4882	52	9	52.15	4.07	0.6119	2.487	0.840
14	17.9784	20.3559	2.3775	56	7	56.12	3.97	0.5994	2.436	0.823
15	17.4819	19.8648	2.3829	60	5	60.08	3.97	0.6007	2.442	0.824
16	18.0275	20.4073	2.3798	64	7	64.12	4.03	0.5900	2.399	0.810
17	18.4090	20.7403	2.3313	68	7	68.12	4.00	0.5828	2.369	0.800
18	18.1027	20.4277	2.3250	72	5	72.08	3.97	0.5861	2.383	0.804
19	17.7800	20.1042	2.3242	76	5	76.08	4.00	0.5810	2.362	0.797
20	18.2999	20.6244	2.3245	80	6	80.10	4.02	0.5787	2.352	0.794
21	18.3227	20.5909	2.2682	84	6	84.10	4.00	0.5671	2.305	0.778
22	17.8238	20.0853	2.2615	88	5	88.08	3.98	0.5677	2.308	0.779
23	17.9996	20.2618	2.2622	92	7	92.12	4.03	0.5609	2.280	0.770
24	17.7721	19.9856	2.2135	96	5	96.08	3.97	0.5580	2.268	0.766
25	18.0101	20.213	2.2029	100	5	100.08	4.00	0.5507	2.239	0.756
26	18.1854	20.3961	2.2107	104	6	104.10	4.02	0.5504	2.237	0.755
27	17.9494	20.1068	2.1574	108	3	108.05	3.95	0.5462	2.220	0.750
28	17.659	19.8728	2.2138	112	9	112.15	4.10	0.5400	2.195	0.741
29	18.2091	20.4758	2.2667	116	20	116.33	4.18	0.5418	2.203	0.744
30	18.1649	20.271	2.1061	120	13	120.22	3.88	0.5423	2.205	0.744



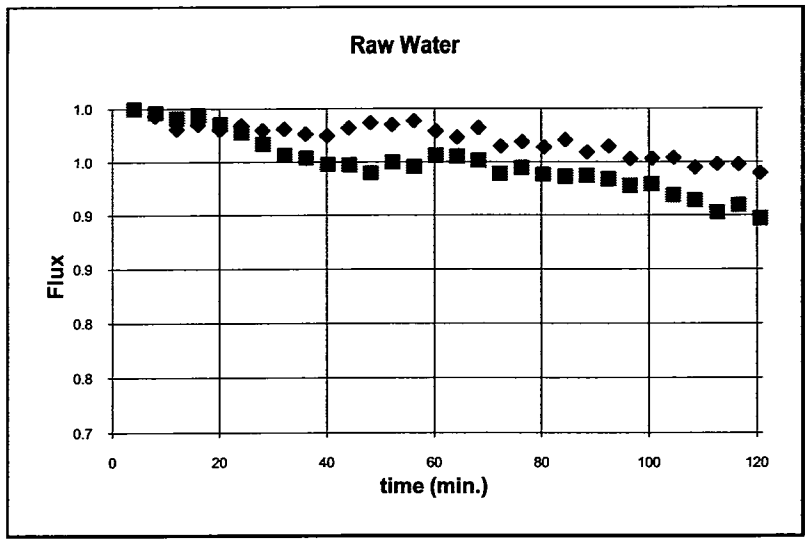
Sample Number	Flask (g)	Flask + Sample (g)	Sample (g)	Time		Time (min)		Flowrate (g/min)	Flux (10^{-5} m/s)	J/J_O
				Min	Sec	Total	Diff.			
1	18.3232	21.8439	3.5207	4	3	4.05	4.05	0.8693	3.534	1.000
2	17.7607	21.1971	3.4364	8	3	8.05	4.00	0.8591	3.492	0.988
3	18.0124	21.4551	3.4427	12	4	12.07	4.02	0.8571	3.484	0.986
4	17.4710	20.9171	3.4461	16	6	16.10	4.03	0.8544	3.473	0.983
5	17.5815	20.9372	3.3557	20	4	20.07	3.97	0.8460	3.439	0.973
6	17.8463	21.2497	3.4034	24	5	24.08	4.02	0.8473	3.444	0.975
7	18.0980	21.4579	3.3599	28	3	28.05	3.97	0.8470	3.443	0.974
8	17.8882	21.2960	3.4078	32	5	32.08	4.03	0.8449	3.435	0.972
9	18.3861	21.7490	3.3629	36	5	36.08	4.00	0.8407	3.418	0.967
10	17.9677	21.3329	3.3652	40	5	40.08	4.00	0.8413	3.420	0.968
11	18.0243	21.3900	3.3657	44	6	44.10	4.02	0.8379	3.406	0.964
12	17.7093	21.0292	3.3199	48	3	48.05	3.95	0.8405	3.417	0.967
13	17.9178	21.2856	3.3678	52	5	52.08	4.03	0.8350	3.394	0.960
14	17.9773	21.3467	3.3694	56	7	56.12	4.03	0.8354	3.396	0.961
15	17.4808	20.7718	3.2910	60	5	60.08	3.97	0.8297	3.373	0.954
16	18.0269	21.3454	3.3185	64	5	64.08	4.00	0.8296	3.372	0.954
17	18.4081	21.7449	3.3368	68	7	68.12	4.03	0.8273	3.363	0.952
18	18.1017	21.3985	3.2968	72	6	72.10	3.98	0.8276	3.364	0.952
19	17.7791	21.1024	3.3233	76	7	76.12	4.02	0.8274	3.363	0.952
20	18.2993	21.5757	3.2764	80	6	80.10	3.98	0.8225	3.344	0.946
21	18.3225	21.6029	3.2804	84	7	84.12	4.02	0.8167	3.320	0.939
22	17.8233	21.0887	3.2654	88	7	88.12	4.00	0.8164	3.318	0.939
23	17.9991	21.2372	3.2381	92	5	92.08	3.97	0.8163	3.318	0.939
24	17.7719	21.0493	3.2774	96	7	96.12	4.03	0.8126	3.303	0.935
25	18.0099	21.3030	3.2931	100	9	100.15	4.03	0.8165	3.319	0.939
26	18.1848	21.5002	3.3154	104	14	104.23	4.08	0.8119	3.301	0.934
27	17.9490	21.1882	3.2392	108	12	108.20	3.97	0.8166	3.320	0.939
28	17.6586	20.9957	3.3371	112	18	112.30	4.10	0.8139	3.309	0.936
29	18.2090	21.3960	3.1870	116	16	116.27	3.97	0.8034	3.266	0.924
30	18.1648	21.4033	3.2385	120	16	120.27	4.00	0.8096	3.291	0.931

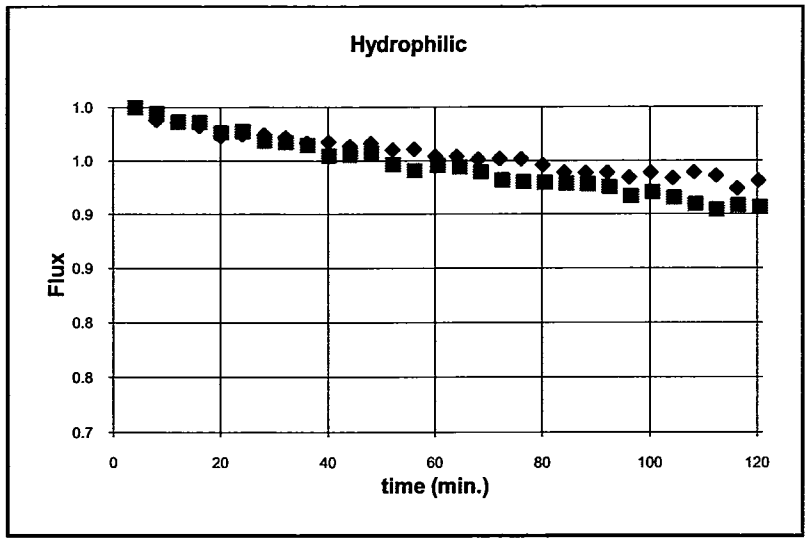


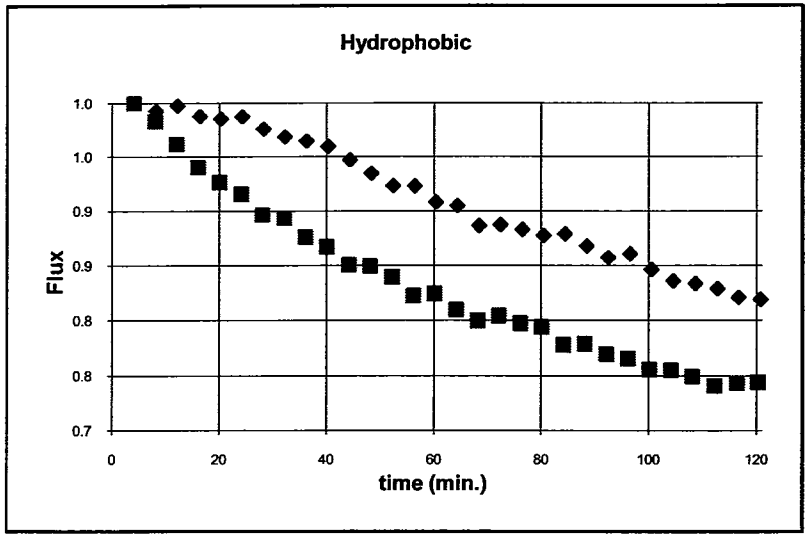
Sample Number	Flask (g)	Flask + Sample (g)	Sample (g)	Time		Time (min)		Flowrate (g/min)	Flux (10^{-5} m/s)	J/J_O
				Min	Sec	Total	Diff.			
1	18.3221	21.7069	3.3848	4	6	4.10	4.10	0.8256	3.356	1.000
2	17.7594	21.0570	3.2976	8	7	8.12	4.02	0.8210	3.337	0.994
3	18.0109	21.2687	3.2578	12	7	12.12	4.00	0.8145	3.311	0.987
4	17.4697	20.7261	3.2564	16	7	16.12	4.00	0.8141	3.309	0.986
5	17.5801	20.7916	3.2115	20	6	20.10	3.98	0.8062	3.277	0.977
6	17.8449	21.1003	3.2554	24	8	24.13	4.03	0.8071	3.281	0.978
7	18.0968	21.3087	3.2119	28	9	28.15	4.02	0.7996	3.251	0.969
8	17.8872	21.0553	3.1681	32	7	32.12	3.97	0.7987	3.247	0.967
9	18.3853	21.5970	3.2117	36	9	36.15	4.03	0.7963	3.237	0.965
10	17.9667	21.1063	3.1396	40	8	40.13	3.98	0.7882	3.204	0.955
11	18.0235	21.1657	3.1422	44	7	44.12	3.98	0.7888	3.207	0.955
12	17.7082	20.8567	3.1485	48	6	48.10	3.98	0.7904	3.213	0.957
13	17.9168	21.0818	3.1650	52	9	52.15	4.05	0.7815	3.177	0.947
14	17.9763	21.0965	3.1202	56	10	56.17	4.02	0.7768	3.158	0.941
15	17.4799	20.9155	3.4356	60	34	60.57	4.40	0.7808	3.174	0.946
16	18.0259	21.2090	3.1831	64	39	64.65	4.08	0.7795	3.169	0.944
17	18.4071	21.4841	3.0770	68	37	68.62	3.97	0.7757	3.153	0.940
18	18.1010	21.1398	3.0388	72	34	72.57	3.95	0.7693	3.127	0.932
19	17.7782	20.8255	3.0473	76	32	76.53	3.97	0.7682	3.123	0.931
20	18.2983	21.3686	3.0703	80	32	80.53	4.00	0.7676	3.120	0.930
21	18.3208	21.3496	3.0288	84	29	84.48	3.95	0.7668	3.117	0.929
22	17.8218	20.8743	3.0525	88	28	88.47	3.98	0.7663	3.115	0.928
23	17.9977	21.0412	3.0435	92	27	92.45	3.98	0.7641	3.106	0.925
24	17.7711	20.8243	3.0532	96	29	96.48	4.03	0.7570	3.077	0.917
25	18.0088	21.0111	3.0023	100	26	100.43	3.95	0.7601	3.090	0.921
26	18.1838	21.2322	3.0484	104	28	104.47	4.03	0.7558	3.072	0.915
27	17.9477	20.9509	3.0032	108	28	108.47	4.00	0.7508	3.052	0.909
28	17.6577	20.6061	2.9484	112	25	112.42	3.95	0.7464	3.034	0.904
29	18.2078	21.2072	2.9994	116	25	116.42	4.00	0.7499	3.048	0.908
30	18.1638	21.2573	3.0935	120	33	120.55	4.13	0.7484	3.042	0.907



comparison







blue=untreated membrane
red=charged membrane

experiment_HA_2009-01-28.xls

New Membrane

weight (g)	17.87	18.1453	18.7023	19.452	20.4671	21.7569
Δweight (g)		0.2753	0.557	0.7497	1.0151	1.2898
Time (s)		64	64	58	60	60
Pressure (MPa)		0.0201	0.0401	0.0602	0.0807	0.0997
Flux (L/hr*m^2)		37.769817	76.417683	113.49537	148.55122	188.75122

Slope 1871.8 R Squared 0.9991

PreAdsorption

weight (g)	21.3273	21.5778	22.0862	22.8133	23.7623	24.9735
Δweight (g)		0.2505	0.5084	0.7271	0.949	1.2112
Time (s)		60	61	59	59	61
Pressure (MPa)		0.0203	0.0404	0.06	0.0797	0.0992
Flux (L/hr*m^2)		36.658537	73.180328	108.20835	141.23191	174.34306

Slope 1742.5 R Squared 0.9997

After Filtration

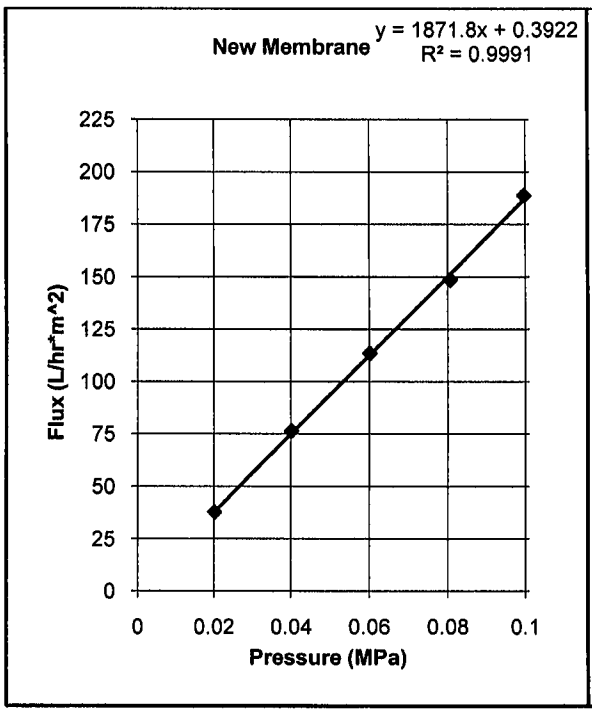
weight (g)	17.8675	18.1609	18.706	19.5059	20.5638	21.8822
Δweight (g)		0.2934	0.5451	0.7999	1.0579	1.3184
Time (s)		67	61	60	60	60
Pressure (MPa)		0.02	0.0403	0.06	0.0794	0.0999
Flux (L/hr*m^2)		38.450673	78.463015	117.05854	154.81463	192.93659

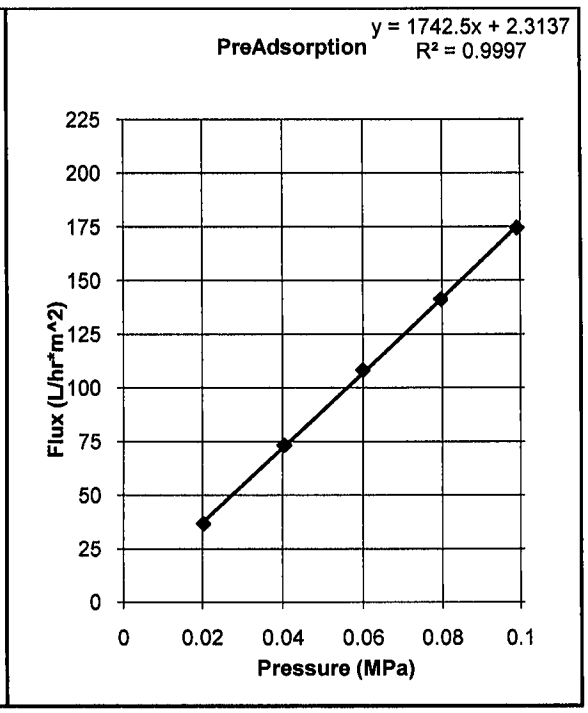
Slope 1937.2 R Squared 0.9999

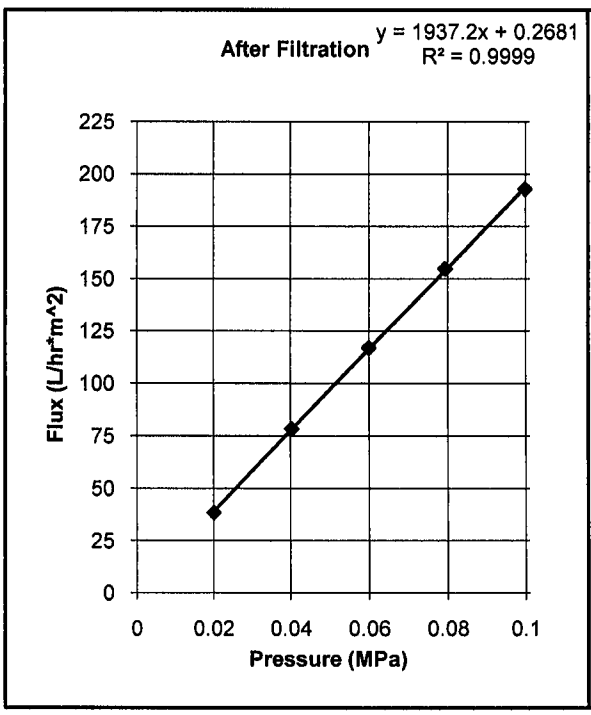
After Cleaning

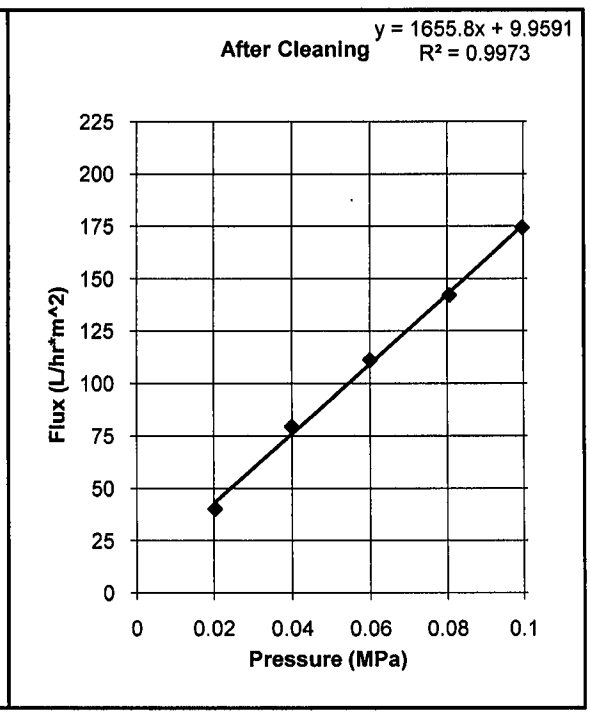
weight (g)	17.8668	18.1648	18.7177	19.5281	20.5481	21.7792
Δweight (g)		0.298	0.5529	0.8104	1.02	1.2311
Time (s)		65	61	64	63	62
Pressure (MPa)		0.0203	0.0399	0.06	0.0806	0.0998
Flux (L/hr*m^2)		40.255159	79.585766	111.18293	142.16028	174.34933

Slope 1655.8 R Squared 0.9973


New Membrane
y = 1871.8x + 0.3922
R² = 0.9991
Flux (L/hr*m^2)
Pressure (MPa)
0
25
50
75
100
125
150
175
200
225
0
0.02
0.04
0.06
0.08
0.1


PreAdsorption
y = 1742.5x + 2.3137
R² = 0.9997
Flux (L/hr*m^2)
Pressure (MPa)
0
25
50
75
100
125
150
175
200
225
0
0.02
0.04
0.06
0.08
0.1


After Filtration
y = 1937.2x + 0.2681
R² = 0.9999
Flux (L/hr*m^2)
Pressure (MPa)
0
25
50
75
100
125
150
175
200
225
0
0.02
0.04
0.06
0.08
0.1


After Cleaning
y = 1655.8x + 9.9591
R² = 0.9973
Flux (L/hr*m^2)
Pressure (MPa)
0
25
50
75
100
125
150
175
200
225
0
0.02
0.04
0.06
0.08
0.1

New Membrane

weight (g)	17.9476	18.177	18.6921	19.4488	20.4501	21.7001
Δweight (g)		0.2294	0.5151	0.7567	1.0013	1.25
Time (s)		59	62	61	60	61
Pressure (MPa)		0.02	0.0403	0.0599	0.0803	0.0995
Flux (L/hr*m^2)		34.139727	72.948859	108.92123	146.53171	179.92803

Slope 1835.2 R Squared 0.9997

After Modification

weight (g)	17.8626	18.1105	18.6041	19.379	20.3843	21.6494
Δweight (g)		0.2479	0.4936	0.7749	1.0053	1.2651
Time (s)		60	59	62	60	61
Pressure (MPa)		0.0199	0.0397	0.0599	0.0795	0.0998
Flux (L/hr*m^2)		36.278049	73.458454	109.74194	147.11707	182.10156

Slope 1830.1 R Squared 0.9998

PreAdsorption

weight (g)	17.8707	18.127	18.604	19.3048	20.2353	21.4067
Δweight (g)		0.2563	0.477	0.7008	0.9305	1.1714
Time (s)		65	65	60	60	61
Pressure (MPa)		0.0205	0.04	0.0599	0.0802	0.1002
Flux (L/hr*m^2)		34.622139	64.435272	102.5561	136.17073	168.61415

Slope 1702.1 R Squared 0.999

After Filtration

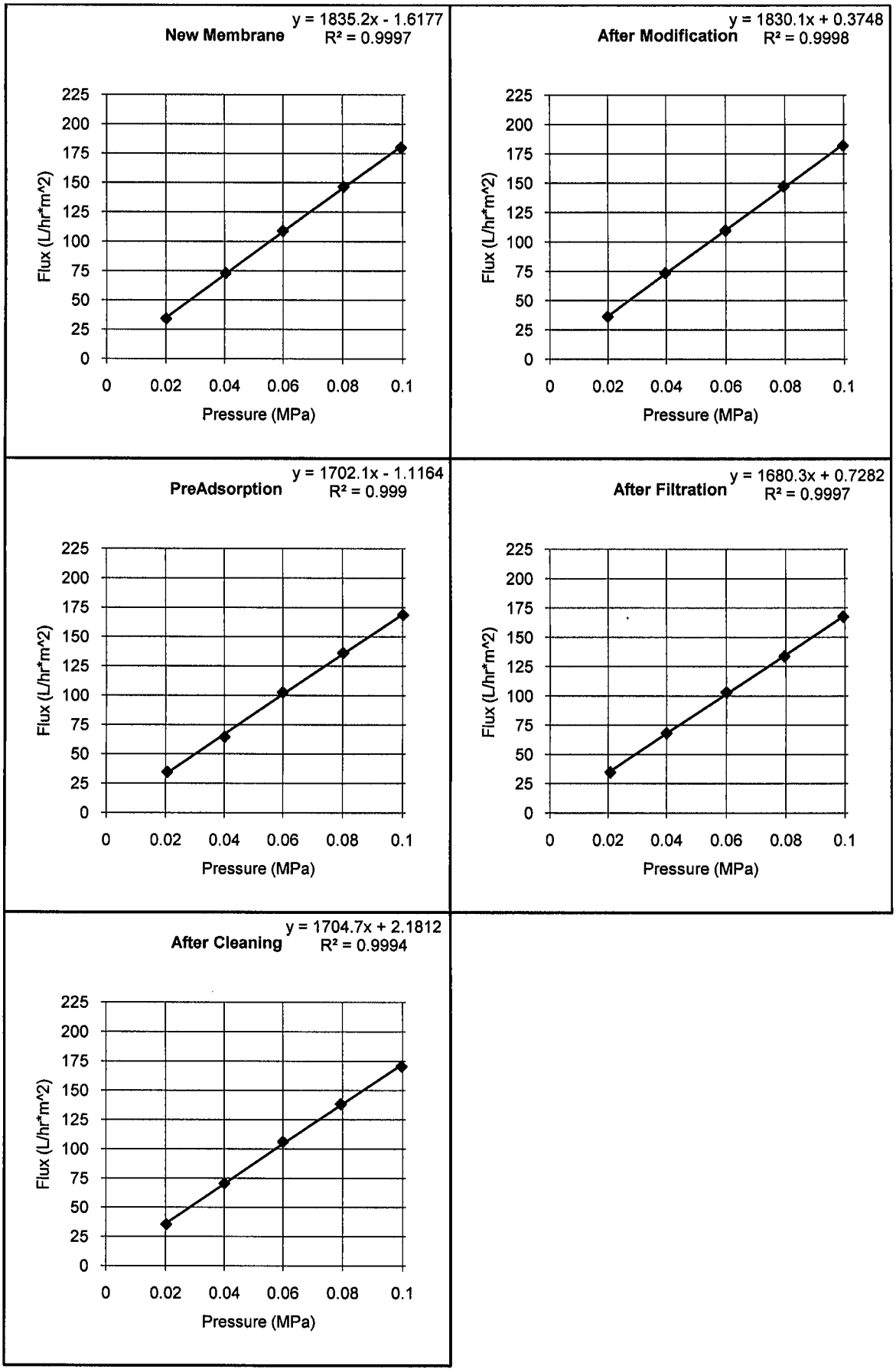
weight (g)	17.8676	18.101	18.5745	19.2902	20.2045	21.3682
Δweight (g)		0.2334	0.4735	0.7157	0.9143	1.1637
Time (s)		59	61	61	60	61
Pressure (MPa)		0.0207	0.04	0.06	0.0795	0.0995
Flux (L/hr*m^2)		34.735014	68.156737	103.01959	133.8	167.5058

Slope 1680.3 R Squared 0.9997

After Cleaning

weight (g)	17.871	18.1375	18.6195	19.3204	20.2974	21.4429
Δweight (g)		0.2665	0.482	0.7009	0.977	1.1455
Time (s)		66	60	58	62	59
Pressure (MPa)		0.0202	0.04	0.06	0.0794	0.0996
Flux (L/hr*m^2)		35.454545	70.536585	106.10765	138.36349	170.4754

Slope 1704.7 R Squared 0.9994


New Membrane
y = 1835.2x - 1.6177
R² = 0.9997
After Modification
y = 1830.1x + 0.3748
R² = 0.9998
PreAdsorption
y = 1702.1x - 1.1164
R² = 0.999
After Filtration
y = 1680.3x + 0.7282
R² = 0.9997
After Cleaning
y = 1704.7x + 2.1812
R² = 0.9994
Flux (L/hr*m^2)
Pressure (MPa)
0
25
50
75
100
125
150
175
200
225
0.02
0.04
0.06
0.08
0.1

New Membrane

weight (g)	21.4381	21.7287	22.2185	23.0007	24.0054	25.3052
Δweight (g)		0.2906	0.4898	0.7822	1.0047	1.2998
Time (s)		67	56	61	59	60
Pressure (MPa)		0.02	0.0397	0.0594	0.0792	0.0991
Flux (L/hr*m^2)		38.083728	76.797909	112.59176	149.52129	190.21463

Slope 1906.9 R Squared 0.9996

PreAdsorption

weight (g)	17.8639	18.2025	18.753	19.5665	20.6449	21.907
Δweight (g)		0.3386	0.5505	0.8135	1.0784	1.2621
Time (s)		73	60	60	61	59
Pressure (MPa)		0.0204	0.04	0.0598	0.0799	0.0996
Flux (L/hr*m^2)		40.72703	80.560976	119.04878	155.22751	187.82803

Slope 1860 R Squared 0.9983

After Filtration

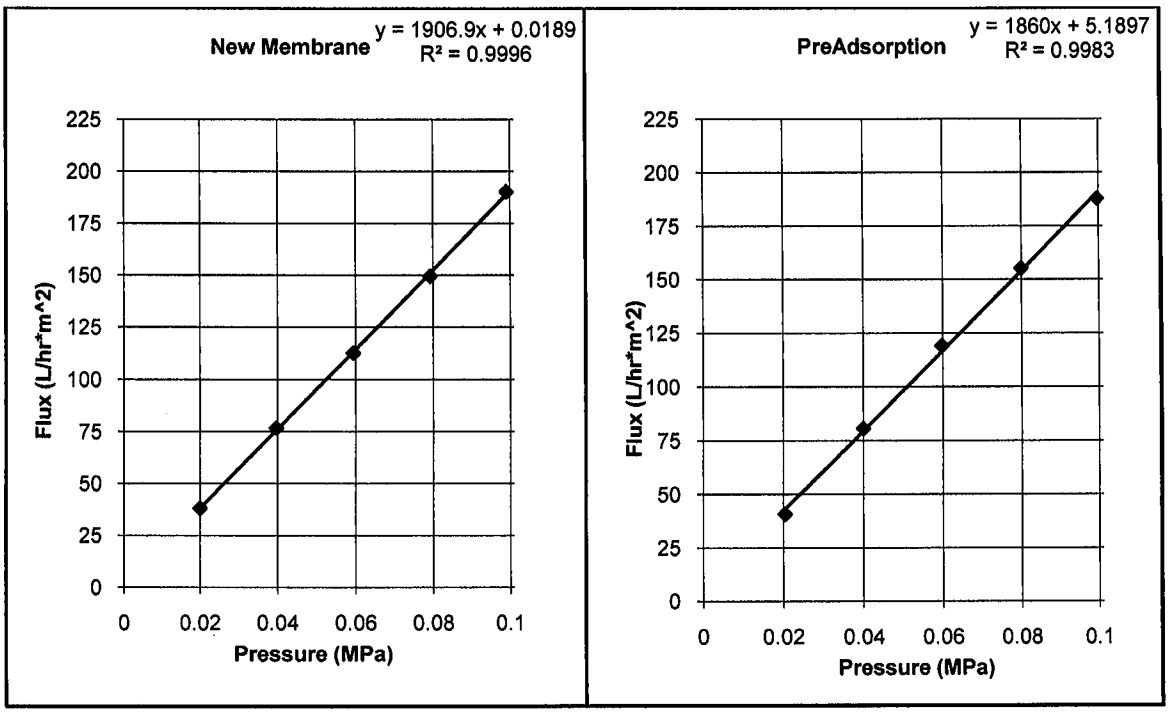
weight (g)	17.876	18.1661	18.7583	19.6531	20.8058	22.2165
Δweight (g)		0.2901	0.5922	0.8948	1.1527	1.4107
Time (s)		61	62	62	61	60
Pressure (MPa)		0.0202	0.0401	0.0598	0.0793	0.0995
Flux (L/hr*m^2)		41.757697	83.867821	126.72227	165.92243	206.4439

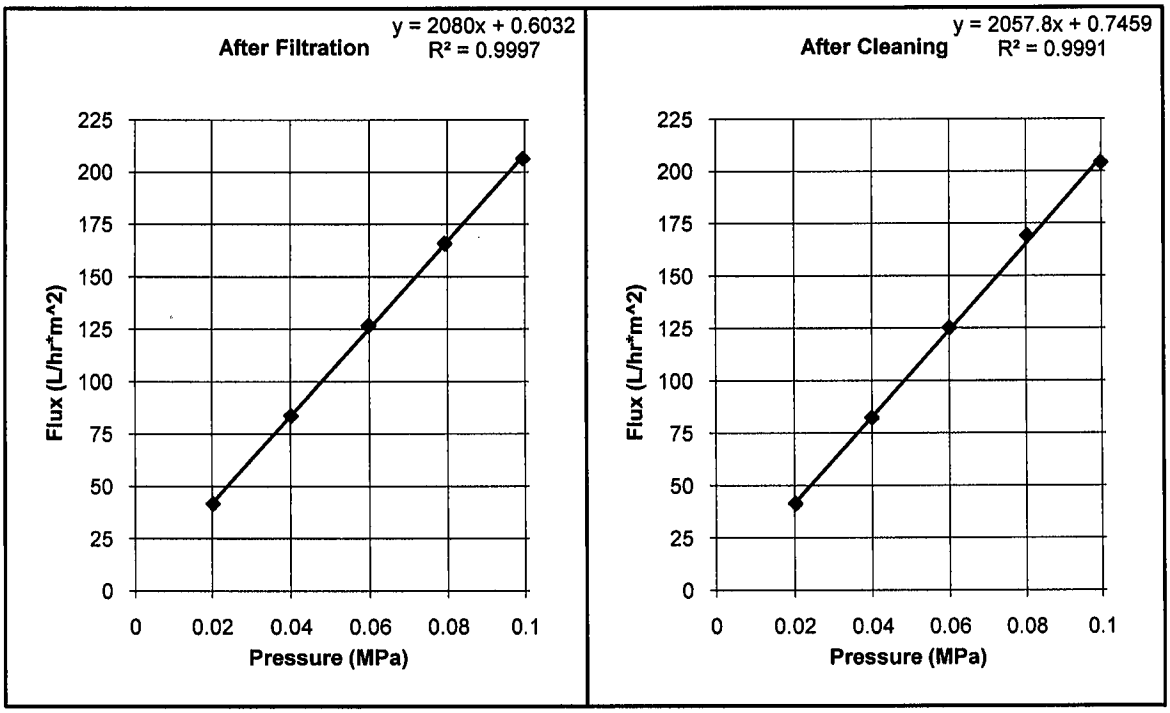
Slope 2080 R Squared 0.9997

After Cleaning

weight (g)	17.9499	18.2665	18.82	19.7041	20.8782	22.2957
Δweight (g)		0.3166	0.5535	0.8841	1.1741	1.4175
Time (s)		67	59	62	61	61
Pressure (MPa)		0.0202	0.0399	0.06	0.0804	0.1
Flux (L/hr*m^2)		41.491081	82.372881	125.20692	169.0028	204.03838

Slope 2057.8 R Squared 0.9991


New Membrane
y = 1906.9x + 0.0189
R² = 0.9996
Flux (L/hr*m^2)
Pressure (MPa)
PreAdsorption
y = 1860x + 5.1897
R² = 0.9983
Flux (L/hr*m^2)
Pressure (MPa)


After Filtration
y = 2080x + 0.6032
R² = 0.9997
Flux (L/hr*m^2)
Pressure (MPa)
After Cleaning
y = 2057.8x + 0.7459
R² = 0.9991
Flux (L/hr*m^2)
Pressure (MPa)

New Membrane

weight (g)	17.9049	18.1502	18.6447	19.3933	20.3979	21.6603
Δweight (g)		0.2453	0.4945	0.7486	1.0046	1.2624
Time (s)		59	60	60	61	61
Pressure (MPa)		0.0201	0.0397	0.0601	0.0796	0.1
Flux (L/hr*m^2)		36.505994	72.365854	109.55122	144.60456	181.71291

Slope 1816 R Squared 1

After Modification

weight (g)	17.8739	18.1085	18.5846	19.257	20.1788	21.3036
Δweight (g)		0.2346	0.4761	0.6724	0.9218	1.1248
Time (s)		63	63	60	61	62
Pressure (MPa)		0.0201	0.04	0.0601	0.0804	0.1
Flux (L/hr*m^2)		32.696864	66.355401	98.4	132.68613	159.29504

Slope 1596.3 R Squared 0.9987

PreAdsorption

weight (g)	17.8694	18.0955	18.5503	19.2445	20.0802	21.1557
Δweight (g)		0.2261	0.4548	0.6942	0.8357	1.0755
Time (s)		62	62	64	59	62
Pressure (MPa)		0.0202	0.0404	0.0603	0.0797	0.0997
Flux (L/hr*m^2)		32.020456	64.409127	95.240854	124.3704	152.31314

Slope 1515.7 R Squared 0.9993

After Filtration

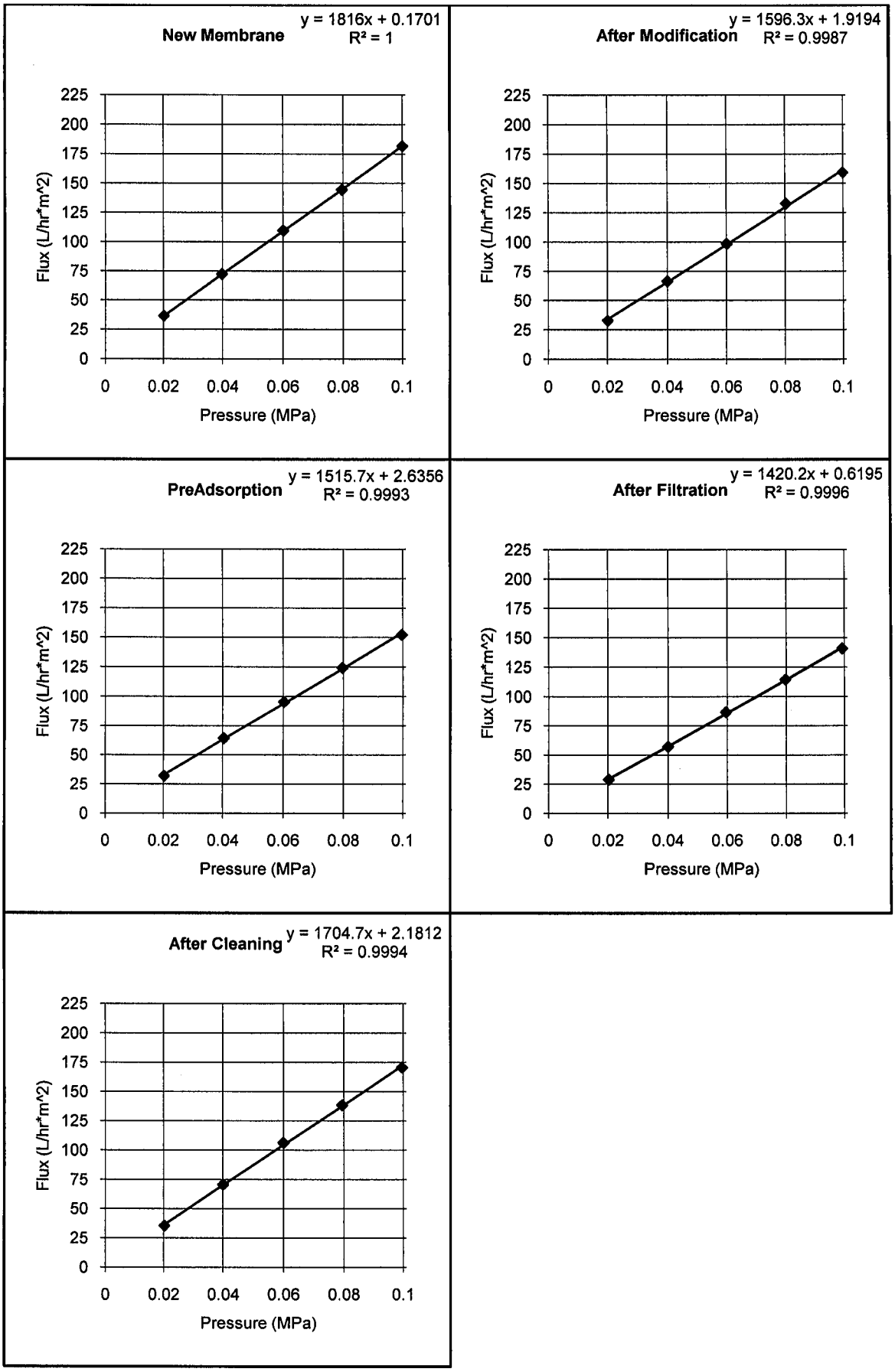
weight (g)	17.8691	18.073	18.4834	19.1041	19.8862	20.8798
Δweight (g)		0.2039	0.4104	0.6207	0.7821	0.9936
Time (s)		62	63	63	60	62
Pressure (MPa)		0.0203	0.04	0.0596	0.0798	0.0993
Flux (L/hr*m^2)		28.876475	57.198606	86.508711	114.45366	140.7144

Slope 1420.2 R Squared 0.9996

After Cleaning

weight (g)	17.8635	18.0914	18.5448	19.1698	19.9669	20.9983
Δweight (g)		0.2279	0.4534	0.625	0.7971	1.0314
Time (s)		64	66	61	59	61
Pressure (MPa)		0.0201	0.0401	0.06	0.0799	0.1004
Flux (L/hr*m^2)		31.266768	60.31929	89.964014	118.62588	148.46222

Slope 1460.5 R Squared 1


New Membrane
y = 1816x + 0.1701
R² = 1
After Modification
y = 1596.3x + 1.9194
R² = 0.9987
PreAdsorption
y = 1515.7x + 2.6356
R² = 0.9993
After Filtration
y = 1420.2x + 0.6195
R² = 0.9996
After Cleaning
y = 1704.7x + 2.1812
R² = 0.9994
Flux (L/hr*m^2)
Pressure (MPa)
0
25
50
75
100
125
150
175
200
225
0.02
0.04
0.06
0.08
0.1

New Membrane

weight (g)	17.8631	18.1004	18.6227	19.3898	20.405	21.6215
Δweight (g)		0.2373	0.5223	0.7671	1.0152	1.2165
Time (s)		57	64	62	62	60
Pressure (MPa)		0.0201	0.0398	0.06	0.0803	0.0996
Flux (L/hr*m^2)		36.554557	71.657012	108.63729	143.77341	178.02439

Slope 1779.7 R Squared 0.9999

PreAdsorption

weight (g)	17.8983	18.1299	18.6552	19.409	20.3909	21.6099
Δweight (g)		0.2316	0.5253	0.7538	0.9819	1.219
Time (s)		63	64	61	60	61
Pressure (MPa)		0.0201	0.0398	0.0597	0.0801	0.1
Flux (L/hr*m^2)		32.278746	72.068598	108.5038	143.69268	175.46581

Slope 1788.8 R Squared 0.998

After Filtration

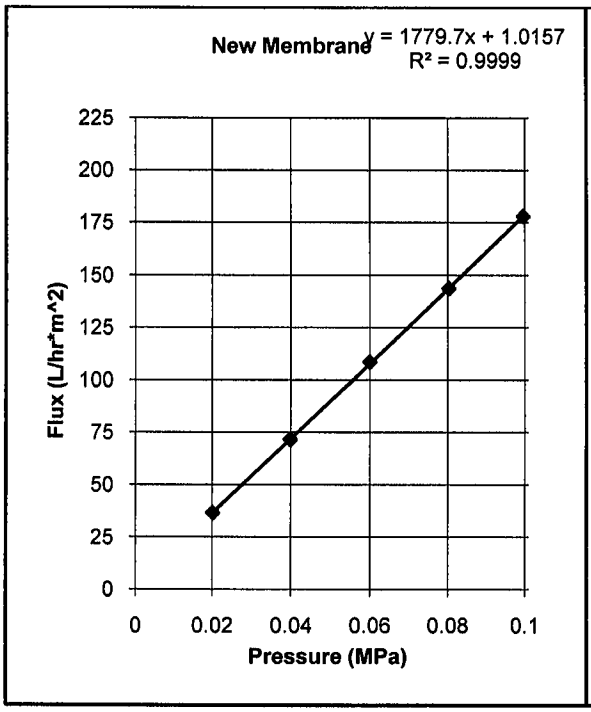
weight (g)	17.8721	18.1525	18.6717	19.4316	20.4367	21.7878
Δweight (g)		0.2804	0.5192	0.7599	1.0051	1.3511
Time (s)		70	64	61	62	67
Pressure (MPa)		0.02	0.04	0.0609	0.0799	0.1
Flux (L/hr*m^2)		35.172125	71.231707	109.38185	142.34304	177.06443

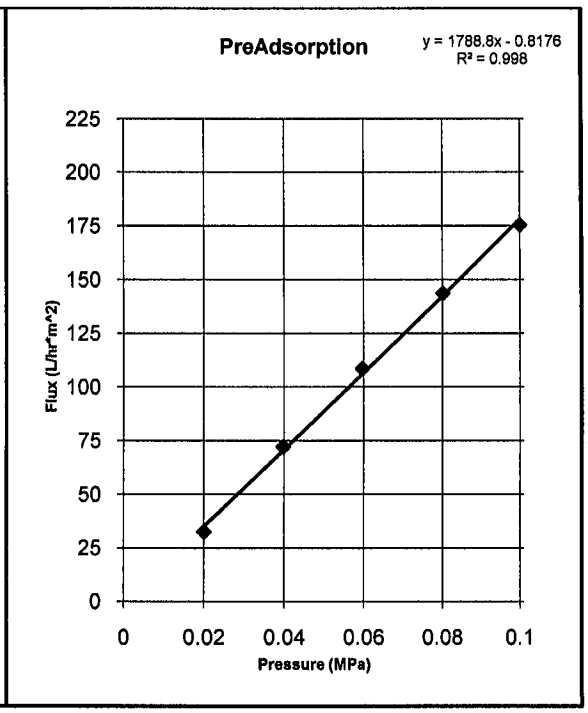
Slope 1775.6 R Squared 0.9998

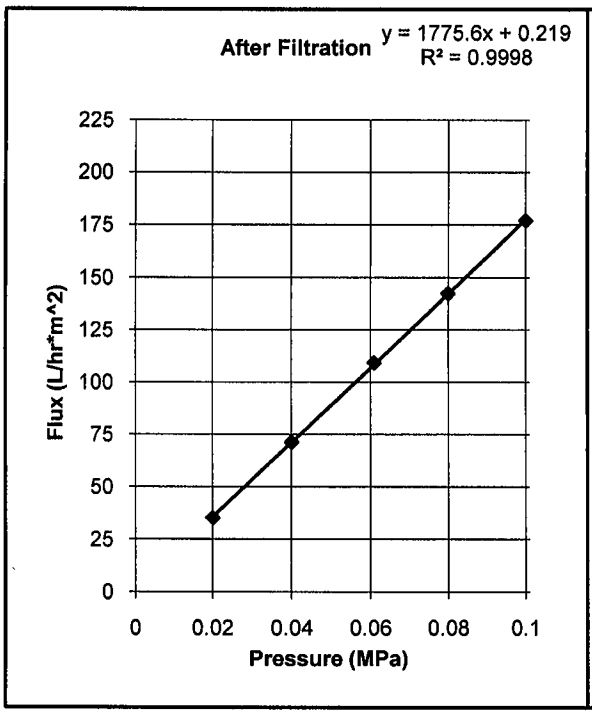
After Cleaning

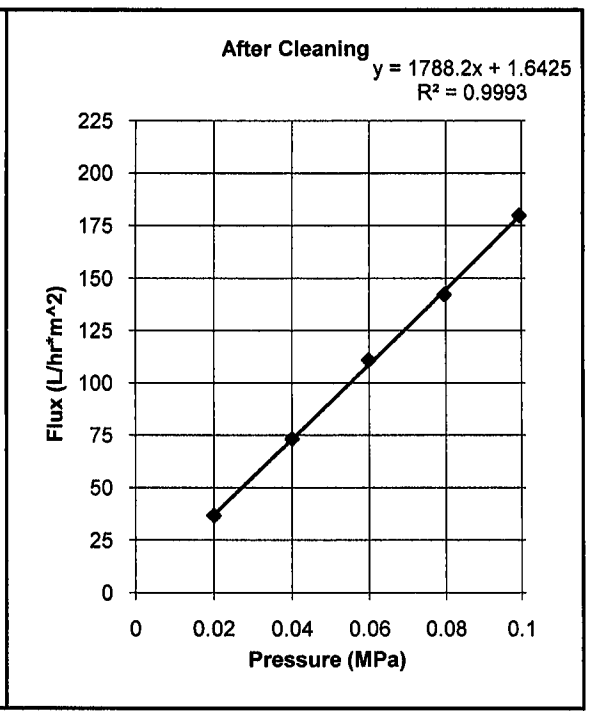
weight (g)	17.868	18.1525	18.6779	19.4485	20.4201	21.6898
Δweight (g)		0.2845	0.5254	0.7706	0.9716	1.2697
Time (s)		68	63	61	60	62
Pressure (MPa)		0.02	0.04	0.0599	0.0796	0.0995
Flux (L/hr*m^2)		36.736011	73.226481	110.92203	142.18537	179.81589

Slope 1788.2 R Squared 0.9993


New Membrane
y = 1779.7x + 1.0157
R² = 0.9999
Flux (L/hr*m^2)
Pressure (MPa)
0
25
50
75
100
125
150
175
200
225
0
0.02
0.04
0.06
0.08
0.1


PreAdsorption
y = 1788.8x - 0.8176
R² = 0.998
Flux (L/hr*m^2)
Pressure (MPa)
0
25
50
75
100
125
150
175
200
225
0
0.02
0.04
0.06
0.08
0.1


After Filtration
y = 1775.6x + 0.219
R² = 0.9998
Flux (L/hr*m^2)
Pressure (MPa)
0
25
50
75
100
125
150
175
200
225
0
0.02
0.04
0.06
0.08
0.1


After Cleaning
y = 1788.2x + 1.6425
R² = 0.9993
Flux (L/hr*m^2)
Pressure (MPa)
0
25
50
75
100
125
150
175
200
225
0
0.02
0.04
0.06
0.08
0.1

New Membrane

weight (g)	17.867	18.146	18.7019	19.4843	20.4963	21.7393
Δweight (g)		0.279	0.5559	0.7824	1.012	1.243
Time (s)		66	66	62	61	60
Pressure (MPa)		0.0203	0.0402	0.0603	0.0798	0.0997
Flux (L/hr*m^2)		37.117517	73.955654	110.80409	145.66973	181.90244

Slope 1821 R Squared 1

After Modification

weight (g)	17.8652	18.106	18.5853	19.2621	20.1888	21.3669
Δweight (g)		0.2408	0.4793	0.6768	0.9267	1.1781
Time (s)		61	61	57	59	60
Pressure (MPa)		0.0203	0.04	0.0601	0.0793	0.0999
Flux (L/hr*m^2)		34.661335	68.991603	104.25674	137.91319	172.40488

Slope 1734.9 R Squared 0.9999

PreAdsorption

weight (g)	17.865	18.1272	18.6066	19.3107	20.3751	21.5364
Δweight (g)		0.2622	0.4794	0.7041	1.0644	1.1613
Time (s)		67	61	60	69	60
Pressure (MPa)		0.0201	0.04	0.06	0.08	0.1001
Flux (L/hr*m^2)		34.361849	69.005998	103.03902	135.44857	169.94634

Slope 1688 R Squared 0.9999

After Filtration

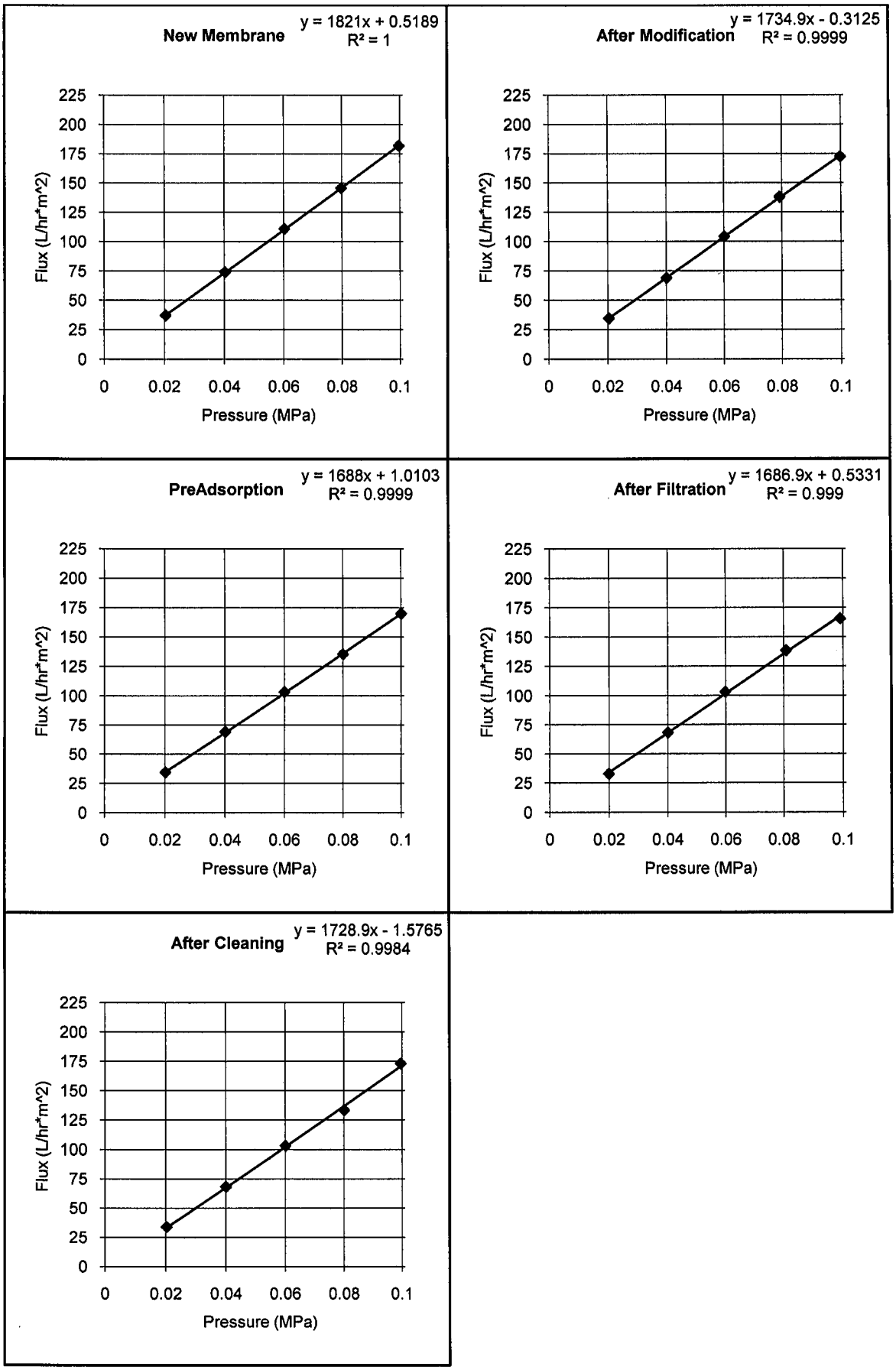
weight (g)	17.8684	18.1074	18.5887	19.3168	20.2466	21.3784
Δweight (g)		0.239	0.4813	0.7281	0.9298	1.1318
Time (s)		64	62	62	59	60
Pressure (MPa)		0.0199	0.04	0.0598	0.0808	0.0991
Flux (L/hr*m^2)		32.789634	68.162077	103.11408	138.37453	165.62927

Slope 1686.9 0.999

After Cleaning

weight (g)	17.8803	18.1108	18.5835	19.2988	20.21	21.3716
Δweight (g)		0.2305	0.4727	0.7153	0.9112	1.1616
Time (s)		60	61	61	60	59
Pressure (MPa)		0.0203	0.04	0.0601	0.0801	0.0996
Flux (L/hr*m^2)		33.731707	68.041583	102.96202	133.34634	172.87143

Slope 1728.9 R Squared 0.9984


New Membrane
y = 1821x + 0.5189
R² = 1
After Modification
y = 1734.9x - 0.3125
R² = 0.9999
PreAdsorption
y = 1688x + 1.0103
R² = 0.9999
After Filtration
y = 1686.9x + 0.5331
R² = 0.999
After Cleaning
y = 1728.9x - 1.5765
R² = 0.9984
Flux (L/hr*m^2)
Pressure (MPa)
0
25
50
75
100
125
150
175
200
225
0.02
0.04
0.06
0.08
0.1

Raw Water								
Non-Modified Membrane					Modified Membrane			
	R^2	L_P	ΔL_P			R^2	L_P	ΔL_P
					New Membrane	0.9997	1835.2	
New Membrane	0.9991	1871.8			After Modification	0.9998	1830.1	-5.1
PreAdsorption	0.9997	1742.5	-129.3		PreAdsorption	0.9990	1702.1	-128.0
After Filtration	0.9999	1937.2	194.7		After Filtration	0.9997	1680.3	-21.8
After Cleaning	0.9973	1655.8	-281.4		After Cleaning	0.9994	1704.7	24.4

HPO Water								
Non-Modified Membrane					Modified Membrane			
	R^2	L_P	ΔL_P			R^2	L_P	ΔL_P
					New Membrane	1.0000	1816.0	
New Membrane	0.9996	1906.9			After Modification	0.9987	1596.3	-219.7
PreAdsorption	0.9983	1860.0	-46.9		PreAdsorption	0.9993	1515.7	-80.6
After Filtration	0.9997	2080.0	220.0		After Filtration	0.9996	1420.2	-95.5
After Cleaning	0.9991	2057.8	-22.2		After Cleaning	1	1460.5	40.3

HPI Water								
Non-Modified Membrane					Modified Membrane			
	R^2	L_P	ΔL_P			R^2	L_P	ΔL_P
					New Membrane	1.0000	1821.0	
New Membrane	0.9999	1779.7			After Modification	0.9999	1734.9	-86.1
PreAdsorption	0.9980	1788.8	9.1		PreAdsorption	0.9999	1688.0	-46.9
After Filtration	0.9998	1775.6	-13.2		After Filtration	0.9990	1686.9	-1.1
After Cleaning	0.9993	1788.2	12.6		After Cleaning	0.9984	1728.9	42.0

RAW WATER							
	Flask (g)	Sample + Flask (g)	Sample (g)	Time		Flow Rate (g/min)	Initial Flux (10^-5
				min	sec		
Non-Modified Membrane							
New Membrane	17.8669	21.369	3.5021	3	58	0.8828824	3.589
PreAdsorption	17.87	21.3273	3.4573	4	0	0.864325	3.514
After Filtration	17.8706	21.5279	3.6573	4	0	0.914325	3.717
After Cleaning	17.8704	21.871	4.0006	4	0	1.00015	4.066
Modified Membrane							
New Membrane	17.8673	21.2481	3.3808	4	0	0.8452	3.436
After Modification	17.8912	21.338	3.4468	3	58	0.8689412	3.532
PreAdsorption	17.8664	21.0714	3.205	4	1	0.7979253	3.244
After Filtration	17.8694	21.073	3.2036	4	2	0.794281	3.229
After Cleaning	17.9006	21.3428	3.4422	4	0	0.86055	3.498

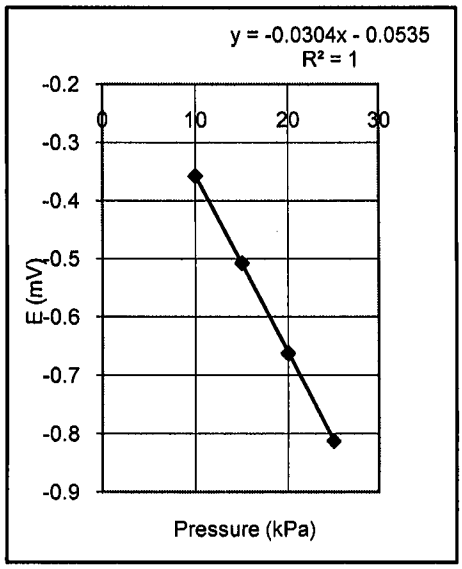
HPO WATER							
	Flask (g)	Sample + Flask (g)	Sample (g)	Time		Flow Rate (g/min)	Initial Flux (10^-5
				min	sec		
Non-Modified Membrane							
New Membrane	17.8707	21.4381	3.5674	4	0	0.89185	3.625
PreAdsorption	17.8666	21.597	3.7304	4	1	0.9287303	3.775
After Filtration	17.8836	21.4381	3.5545	4	0	0.888625	3.612
After Cleaning	17.9042	21.8276	3.9234	4	1	0.9767801	3.971
Modified Membrane							
New Membrane	17.87	21.3098	3.4398	4	0	0.85995	3.496
After Modification	17.9019	20.9654	3.0635	3	58	0.7723109	3.139
PreAdsorption	17.8343	20.808	2.9737	4	1	0.7403402	3.010
After Filtration	17.8651	20.5622	2.6971	4	0	0.674275	2.741
After Cleaning	17.8882	20.7095	2.8213	4	2	0.6994959	2.843

HPI WATER							
	Flask (g)	Sample + Flask (g)	Sample (g)	Time		Flow Rate (g/min)	Initial Flux (10^-5
				min	sec		
Non-Modified Membrane							
New Membrane	17.8666	21.257	3.3904	4	0	0.8476	3.446
PreAdsorption	17.8642	21.2843	3.4201	4	1	0.8514772	3.461
After Filtration	17.8634	21.2512	3.3878	4	0	0.84695	3.443
After Cleaning	17.8634	21.2891	3.4257	4	2	0.8493471	3.453
Modified Membrane							
New Membrane	17.8787	21.2652	3.3865	4	0	0.846625	3.442
After Modification	17.861	21.1069	3.2459	4	0	0.811475	3.299
PreAdsorption	17.8606	21.0738	3.2132	3	59	0.8066611	3.279
After Filtration	17.8644	21.1201	3.2557	4	2	0.8071983	3.281
After Cleaning	17.8861	21.1352	3.2491	4	4	0.798959	3.248

Streaming Potential of Raw

Pressure (kPa)	10	15	20	25
E (mV)	-0.358	-0.508	-0.663	-0.813

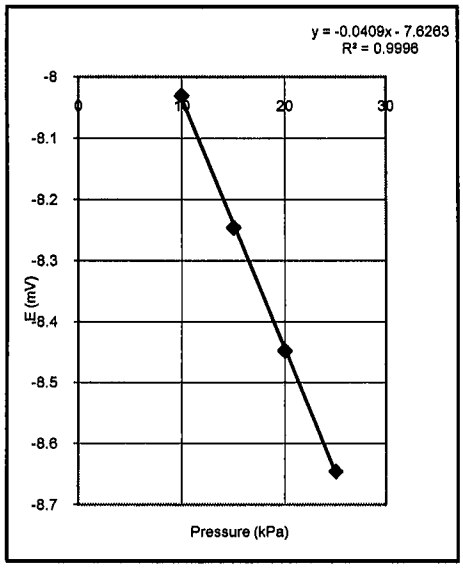
slope	-0.0304
zeta	-5.59
r squared	0.9999



Streaming Potential of HPO

Pressure (kPa)	10	15	20	25
E (mV)	-8.031	-8.246	-8.448	-8.646

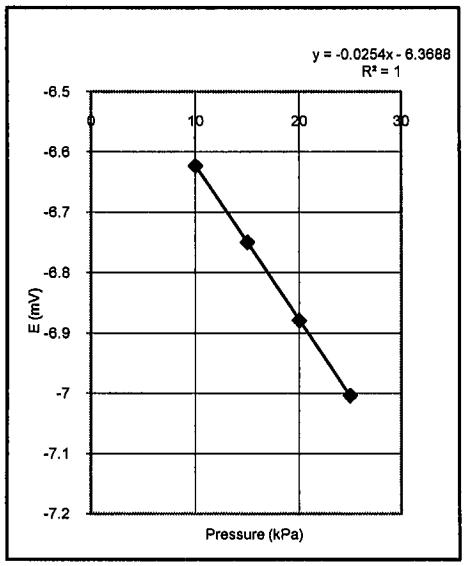
slope	-0.0409
zeta	-7.52
r squared	0.9996



Streaming Potential of HPI

Pressure (kPa)	10	15	20	25
E (mV)	-6.623	-6.75	-6.879	-7.004

slope	-0.0254
zeta	-4.67
r squared	1.0000



Raw Water				
Modified Membrane	Start of Filtration		End of Filtration	
	Prefiltration	Permeate	Prefiltration	Permeate
Absorbance	0.251	0.032	1.389	0.054
DOC	3.82	1.33	18.24	1.96
Rejection (Abs.)	0.8725		0.9611	
Rejection (DOC)	0.6518		0.8925	
Non-Modified Membrane	Start of Filtration		End of Filtration	
	Prefiltration	Permeate	Prefiltration	Permeate
Absorbance	0.250	0.018	1.358	0.033
DOC	3.42	0.71	19.8	0.25
Rejection (Abs.)	0.9280		0.9757	
Rejection (DOC)	0.7924		0.9874	
HPO				
Modified Membrane	Start of Filtration		End of Filtration	
	Prefiltration	Permeate	Prefiltration	Permeate
Absorbance	0.122	0.097	0.267	0.101
DOC	11.8	8.55	12.55	10.2
Rejection (Abs.)	0.2049		0.6217	
Rejection (DOC)	0.2754		0.1873	
	Start of Filtration		End of Filtration	
	Prefiltration	Permeate	Prefiltration	Permeate
Absorbance	0.122	0.071	0.377	0.075
DOC	11.25	8.9	15.45	10.1
Rejection (Abs.)	0.4180		0.8011	
Rejection (DOC)	0.2089		0.3463	
HPI				
Modified Membrane	Start of Filtration		End of Filtration	
	Prefiltration	Permeate	Prefiltration	Permeate
Absorbance	0.008	0.006	0.008	0.007
DOC	6.82	6.68	6.19	6.32
Rejection (Abs.)	0.2500		0.1250	
Rejection (DOC)	0.0205		-0.0210	
Non-Modified Membrane	Start of Filtration		End of Filtration	
	Prefiltration	Permeate	Prefiltration	Permeate
Absorbance	0.009	0.005	0.019	0.007
DOC	6.35	6.05	7.76	6.13
Rejection (Abs.)	0.4444		0.6316	
Rejection (DOC)	0.0472		0.2101	

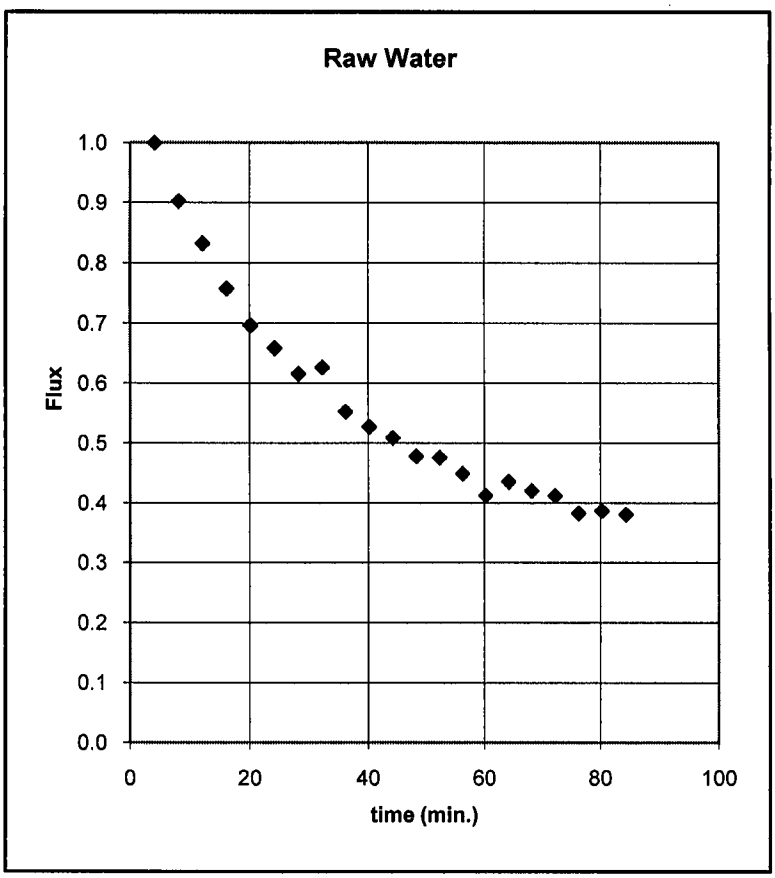
8.3 Appendix Part C

Trial data measured for the experimental procedure for non-modified membranes can be found in this section and consist of 10 pages broken up in the following way:

Table of Contents

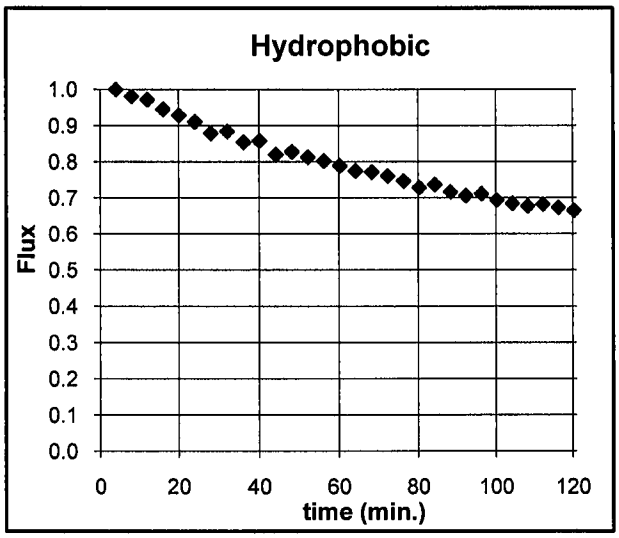
raw water

Sample Number	Flask (g)	Flask + Sample (g)	Sample (g)	Time		Time (min)		Flowrate (g/min)	Flux (10^{-5} m/s)	J/J_O
				Min	Sec	Total	Diff.			
1	18.3189	22.6712	4.3523	4	10	4.17	4.17	1.0446	4.246	1.000
2	17.8473	21.6341	3.7868	8	11	8.18	4.02	0.9428	3.832	0.903
3	18.0193	21.4985	3.4792	12	11	12.18	4.00	0.8698	3.536	0.833
4	17.7678	20.9485	3.1807	16	12	16.20	4.02	0.7919	3.219	0.758
5	18.0020	20.9135	2.9115	20	12	20.20	4.00	0.7279	2.959	0.697
6	18.1835	20.9612	2.7777	24	14	24.23	4.03	0.6887	2.800	0.659
7	17.9437	20.5058	2.5621	28	13	28.22	3.98	0.6432	2.615	0.616
8	17.6515	20.2814	2.6299	32	14	32.23	4.02	0.6547	2.662	0.627
9	18.2589	20.5601	2.3012	36	13	36.22	3.98	0.5777	2.348	0.553
10	18.2187	20.4333	2.2146	40	14	40.23	4.02	0.5514	2.241	0.528
11	18.3760	20.5030	2.1270	44	14	44.23	4.00	0.5318	2.162	0.509
12	17.7637	19.7624	1.9987	48	14	48.23	4.00	0.4997	2.031	0.478
13	17.6454	19.6424	1.9970	52	15	52.25	4.02	0.4972	2.021	0.476
14	17.5266	19.3952	1.8686	56	14	56.23	3.98	0.4691	1.907	0.449
15	17.8839	19.6080	1.7241	60	14	60.23	4.00	0.4310	1.752	0.413
16	17.5610	19.3899	1.8289	64	15	64.25	4.02	0.4553	1.851	0.436
17	18.1272	19.8702	1.7430	68	13	68.22	3.97	0.4394	1.786	0.421
18	17.8970	19.6405	1.7435	72	16	72.27	4.05	0.4305	1.750	0.412
19	17.9834	19.5908	1.6074	76	17	76.28	4.02	0.4002	1.627	0.383
20	17.7815	19.3969	1.6154	80	17	80.28	4.00	0.4038	1.642	0.387
21	18.1591	19.7768	1.6177	84	21	84.35	4.07	0.3978	1.617	0.381



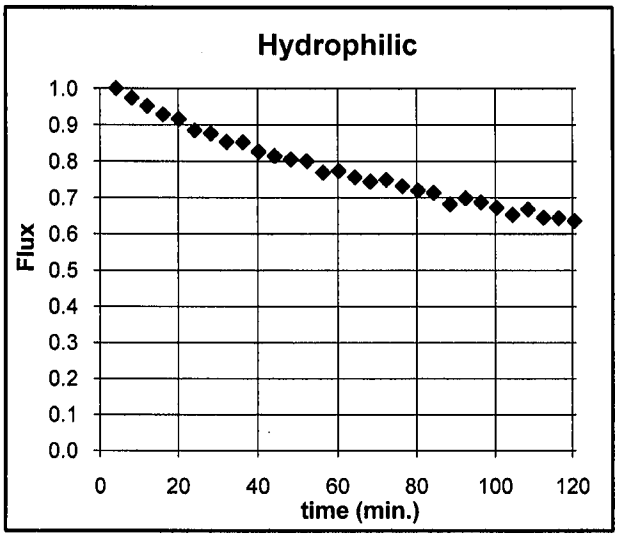
hydrophobic

Sample Number	Flask (g)	Flask + Sample (g)	Sample (g)	Time		Time (min)		Flowrate (g/min)	Flux (10^{-5} m/s)	J/J_O
				Min	Sec	Total	Diff.			
1	18.3204	22.1056	3.7852	4	1	4.02	4.02	0.9424	3.831	1.000
2	17.7626	21.4742	3.7116	8	2	8.03	4.02	0.9240	3.756	0.981
3	18.0118	21.6756	3.6638	12	2	12.03	4.00	0.9160	3.723	0.972
4	17.4689	21.0329	3.5640	16	2	16.03	4.00	0.8910	3.622	0.945
5	17.5805	21.0944	3.5139	20	3	20.05	4.02	0.8748	3.556	0.928
6	17.8437	21.2622	3.4185	24	2	24.03	3.98	0.8582	3.489	0.911
7	18.0886	21.4142	3.3256	28	3	28.05	4.02	0.8280	3.366	0.879
8	17.9096	21.2429	3.3333	32	3	32.05	4.00	0.8333	3.388	0.884
9	18.3861	21.6723	3.2862	36	8	36.13	4.08	0.8048	3.271	0.854
10	17.9706	21.2048	3.2342	40	8	40.13	4.00	0.8085	3.287	0.858
11	18.0201	21.1472	3.1271	44	11	44.18	4.05	0.7721	3.139	0.819
12	17.7078	20.8262	3.1184	48	11	48.18	4.00	0.7796	3.169	0.827
13	17.9130	20.9890	3.0760	52	12	52.20	4.02	0.7658	3.113	0.813
14	17.9720	20.9934	3.0214	56	12	56.20	4.00	0.7554	3.071	0.801
15	17.4762	20.4487	2.9725	60	12	60.20	4.00	0.7431	3.021	0.789
16	18.0301	20.9490	2.9189	64	12	64.20	4.00	0.7297	2.966	0.774
17	18.4093	21.3286	2.9193	68	13	68.22	4.02	0.7268	2.954	0.771
18	18.1046	20.9697	2.8651	72	13	72.22	4.00	0.7163	2.912	0.760
19	17.7786	20.5927	2.8141	76	13	76.22	4.00	0.7035	2.860	0.747
20	18.2958	21.0516	2.7558	80	14	80.23	4.02	0.6861	2.789	0.728
21	18.3206	21.0843	2.7637	84	13	84.22	3.98	0.6938	2.820	0.736
22	17.8494	20.5600	2.7106	88	14	88.23	4.02	0.6748	2.743	0.716
23	18.0213	20.6692	2.6479	92	13	92.22	3.98	0.6647	2.702	0.705
24	17.7685	20.4715	2.7030	96	15	96.25	4.03	0.6702	2.724	0.711
25	18.0010	20.6016	2.6006	100	14	100.23	3.98	0.6529	2.654	0.693
26	18.1825	20.7840	2.6015	104	16	104.27	4.03	0.6450	2.622	0.684
27	17.9436	20.4843	2.5407	108	15	108.25	3.98	0.6378	2.593	0.677
28	17.6506	20.1978	2.5472	112	13	112.22	3.97	0.6422	2.610	0.681
29	18.2574	20.8028	2.5454	116	14	116.23	4.02	0.6337	2.576	0.672
30	18.2172	20.7643	2.5471	120	18	120.30	4.07	0.6263	2.546	0.665



hydrophilic

Sample Number	Flask (g)	Flask + Sample (g)	Sample (g)	Time		Time (min)		Flowrate (g/min)	Flux (10^{-5} m/s)	J/J_O
				Min	Sec	Total	Diff.			
1	18.3204	22.5652	4.2448	4	4	4.07	4.07	1.0438	4.243	1.000
2	17.7621	21.8469	4.0848	8	5	8.08	4.02	1.0170	4.134	0.974
3	18.0114	21.9371	3.9257	12	2	12.03	3.95	0.9938	4.040	0.952
4	17.4691	21.3947	3.9256	16	5	16.08	4.05	0.9693	3.940	0.929
5	17.5803	21.4219	3.8416	20	6	20.10	4.02	0.9564	3.888	0.916
6	17.8434	21.5998	3.7564	24	10	24.17	4.07	0.9237	3.755	0.885
7	18.0883	21.7625	3.6742	28	11	28.18	4.02	0.9147	3.718	0.876
8	17.9092	21.4567	3.5475	32	10	32.17	3.98	0.8906	3.620	0.853
9	18.3852	21.9722	3.5870	36	12	36.20	4.03	0.8893	3.615	0.852
10	17.9696	21.4331	3.4635	40	13	40.22	4.02	0.8623	3.505	0.826
11	18.0197	21.3624	3.3427	44	9	44.15	3.93	0.8498	3.455	0.814
12	17.7071	21.0956	3.3885	48	11	48.18	4.03	0.8401	3.415	0.805
13	17.9126	21.2135	3.3009	52	8	52.13	3.95	0.8357	3.397	0.801
14	17.9715	21.2775	3.3060	56	15	56.25	4.12	0.8031	3.265	0.769
15	17.4758	20.6663	3.1905	60	12	60.20	3.95	0.8077	3.283	0.774
16	18.0297	21.2686	3.2389	64	18	64.30	4.10	0.7900	3.211	0.757
17	18.4085	21.4366	3.0281	68	12	68.20	3.90	0.7764	3.156	0.744
18	18.1030	21.2183	3.1153	72	11	72.18	3.98	0.7821	3.179	0.749
19	17.7782	20.9344	3.1562	76	19	76.32	4.13	0.7636	3.104	0.732
20	18.2952	21.3255	3.0303	80	21	80.35	4.03	0.7513	3.054	0.720
21	18.3203	21.2233	2.9030	84	15	84.25	3.90	0.7444	3.026	0.713
22	17.8488	20.7913	2.9425	88	23	88.38	4.13	0.7119	2.894	0.682
23	18.0203	20.9251	2.9048	92	22	92.37	3.98	0.7292	2.964	0.699
24	17.7687	20.5896	2.8209	96	18	96.30	3.93	0.7172	2.915	0.687
25	18.0006	20.8209	2.8203	100	19	100.32	4.02	0.7021	2.854	0.673
26	18.1817	21.0003	2.8186	104	27	104.45	4.13	0.6819	2.772	0.653
27	17.9422	20.6729	2.7307	108	22	108.37	3.92	0.6972	2.834	0.668
28	17.6500	20.3420	2.6920	112	22	112.37	4.00	0.6730	2.736	0.645
29	18.2562	20.9472	2.6910	116	22	116.37	4.00	0.6728	2.735	0.645
30	18.2165	20.9498	2.7333	120	29	120.48	4.12	0.6640	2.699	0.636



Lp Raw Water

New Membrane

weight (g)	18.382	18.682	19.2817	20.1985	21.3416	22.781
Δweight (g)		0.3	0.5997	0.9168	1.1431	1.4394
Time (s)		60	60	60	60	60
Pressure (MPa)		0.0204	0.0409	0.0602	0.0772	0.0994
Flux (L/hr*m^2)		43.902439	87.760976	134.16585	167.28293	210.6439

2124.9 0.9983

PreAdsorption

weight (g)	17.7916	18.1201	18.7863	19.7558	21.0303	22.5729
Δweight (g)		0.3285	0.6662	0.9695	1.2745	1.5426
Time (s)		60	61	60	61	62
Pressure (MPa)		0.0209	0.0398	0.0595	0.0804	0.0995
Flux (L/hr*m^2)		48.073171	95.894442	141.87805	183.45462	218.4642

2164.4 0.9956

After Filtration

weight (g)	18.0612	18.3577	18.8712	19.6054	20.4685	21.4264
Δweight (g)		0.2965	0.5135	0.7342	0.8631	0.9579
Time (s)		60	60	60	61	61
Pressure (MPa)		0.0203	0.0402	0.061	0.0794	0.0984
Flux (L/hr*m^2)		43.390244	75.146341	107.4439	124.23671	137.88245

1222.6 0.9724

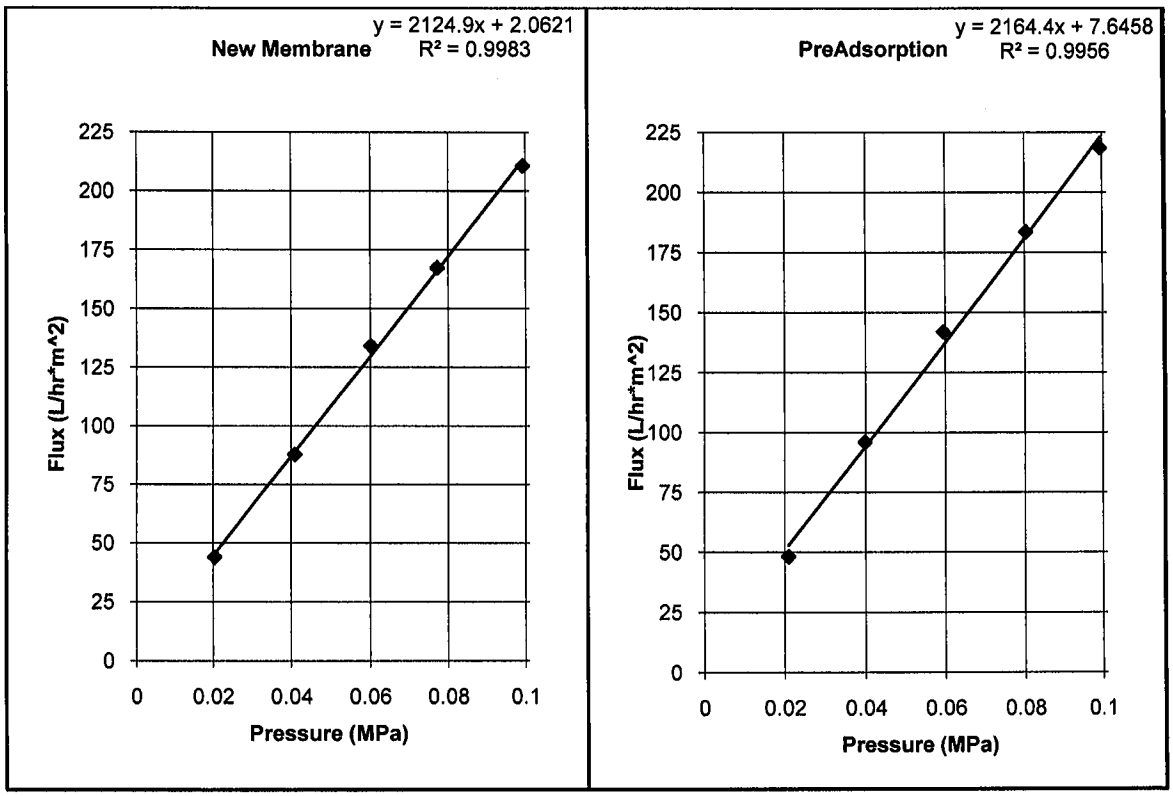
After Cleaning

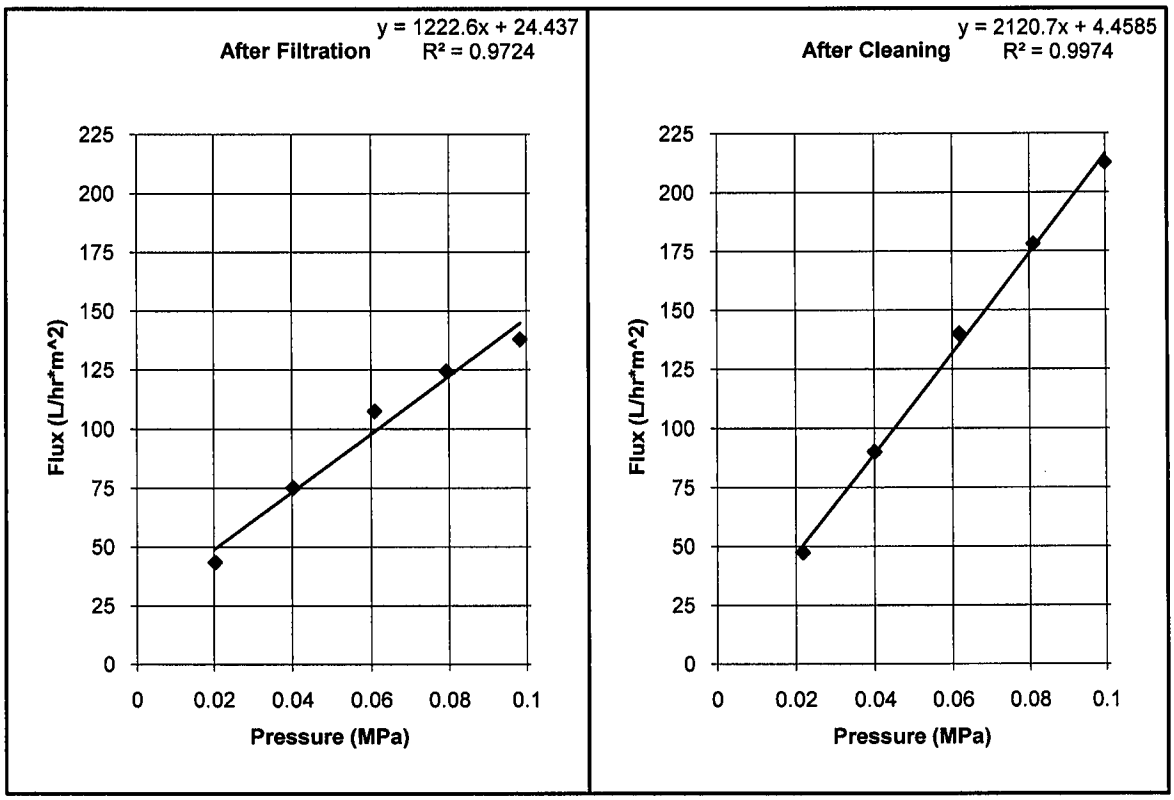
weight (g)	17.5741	17.8978	18.5131	19.4692	20.7263	22.2038
Δweight (g)		0.3237	0.6153	0.9561	1.2571	1.4775
Time (s)		60	60	60	62	61
Pressure (MPa)		0.0217	0.04	0.0618	0.0811	0.0999
Flux (L/hr*m^2)		47.370732	90.043902	139.91707	178.03147	212.67493

2216.9 0.9974

	R^2	L_P	ΔL_P
New Membrane	0.9983	2124.9	
PreAdsorption	0.9956	2164.4	39.5
After Filtration	0.9724	1222.6	-941.8
After Cleaning	0.9974	2216.9	994.3

Lp Raw Water


y = 2124.9x + 2.0621
New Membrane R² = 0.9983
Flux (L/hr*m^2)
Pressure (MPa)
y = 2164.4x + 7.6458
PreAdsorption R² = 0.9956
Flux (L/hr*m^2)
Pressure (MPa)


y = 1222.6x + 24.437
After Filtration R² = 0.9724
Flux (L/hr*m^2)
Pressure (MPa)
y = 2120.7x + 4.4585
After Cleaning R² = 0.9974
Flux (L/hr*m^2)
Pressure (MPa)

New Membrane

weight (g)	18.1144	18.4404	18.9517	19.8034	20.918	22.3026
Δweight (g)		0.326	0.5113	0.8517	1.1146	1.3846
Time (s)		60	60	60	60	60
Pressure (MPa)		0.0201	0.0398	0.0602	0.0799	0.1001
Flux (L/hr*m^2)		47.707317	74.82439	124.63902	163.1122	202.62439

1990.2 0.9949

PreAdsorption

weight (g)	18.0422	18.3291	18.9155	19.8479	21.0121	22.4333
Δweight (g)		0.2869	0.5864	0.9324	1.1642	1.4212
Time (s)		60	60	61	60	60
Pressure (MPa)		0.02	0.0402	0.0603	0.0802	0.1001
Flux (L/hr*m^2)		41.985366	85.814634	134.21192	170.37073	207.98049

2081 0.997

After Filtration

weight (g)	17.8711	18.1602	18.6976	19.5354	20.5801	21.8446
Δweight (g)		0.2891	0.5374	0.8378	1.0447	1.2645
Time (s)		60	60	61	60	60
Pressure (MPa)		0.0202	0.0398	0.0602	0.0801	0.0999
Flux (L/hr*m^2)		42.307317	78.643902	120.59496	152.88293	185.04878

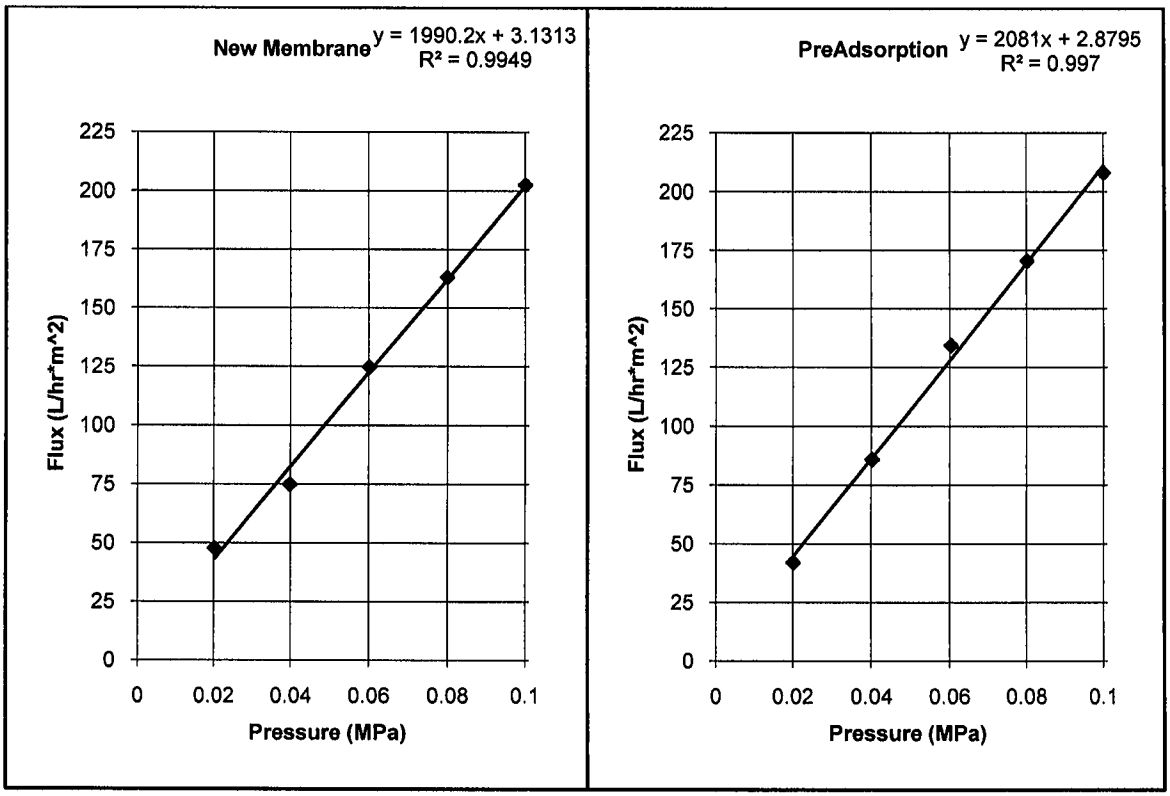
1801.6 0.9976

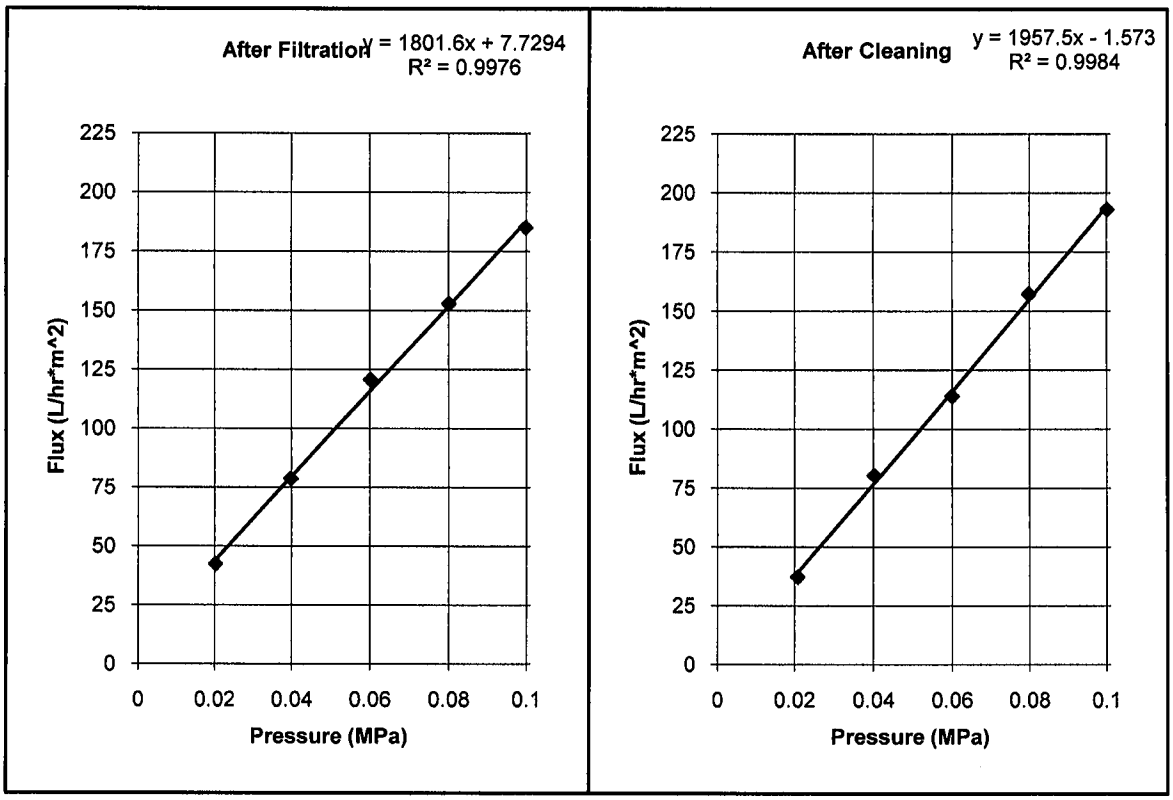
After Cleaning

weight (g)	17.8681	18.1221	18.6795	19.4582	20.5498	21.8689
Δweight (g)		0.254	0.5574	0.7787	1.0916	1.3191
Time (s)		60	61	60	61	60
Pressure (MPa)		0.0208	0.0402	0.06	0.0799	0.1002
Flux (L/hr*m^2)		37.170732	80.233507	113.9561	157.12755	193.03902

1957.5 0.9984

	R^2	L_P	ΔL_P
New Membrane	0.9949	1990.2	
PreAdsorption	0.997	2081	90.8
After Filtration	0.9976	1801.6	-279.4
After Cleaning	0.9984	1957.5	155.9


New Membrane
y = 1990.2x + 3.1313
R² = 0.9949
Flux (L/hr*m^2)
Pressure (MPa)
PreAdsorption
y = 2081x + 2.8795
R² = 0.997
Flux (L/hr*m^2)
Pressure (MPa)


After Filtration
y = 1801.6x + 7.7294
R² = 0.9976
Flux (L/hr*m^2)
Pressure (MPa)
After Cleaning
y = 1957.5x - 1.573
R² = 0.9984
Flux (L/hr*m^2)
Pressure (MPa)

New Membrane

weight (g)	17.8712	18.1557	18.7313	19.5617	20.694	22.0857
Δweight (g)		0.2845	0.5756	0.8304	1.1323	1.3917
Time (s)		60	61	60	60	61
Pressure (MPa)		0.0207	0.0392	0.0584	0.0801	0.0996
Flux (L/hr*m^2)		41.634146	82.853259	121.52195	165.70244	200.32467

2013.2 0.9987

PreAdsorption

weight (g)	17.8669	18.2413	18.9592	19.9829	21.3168	22.9697
Δweight (g)		0.3744	0.7179	1.0237	1.3339	1.6529
Time (s)		61	60	60	61	59
Pressure (MPa)		0.0203	0.0407	0.0606	0.0799	0.1
Flux (L/hr*m^2)		53.892043	105.05854	149.80976	192.0048	245.9876

2372.7 0.9988

After Filtration

weight (g)	18.0423	18.3336	18.9681	19.8231	20.9457
Δweight (g)		0.2913	0.6345	0.855	1.1226
Time (s)		60	63	60	61
Pressure (MPa)		0.0209	0.0403	0.0599	0.08
Flux (L/hr*m^2)		42.629268	88.432056	125.12195	161.58976

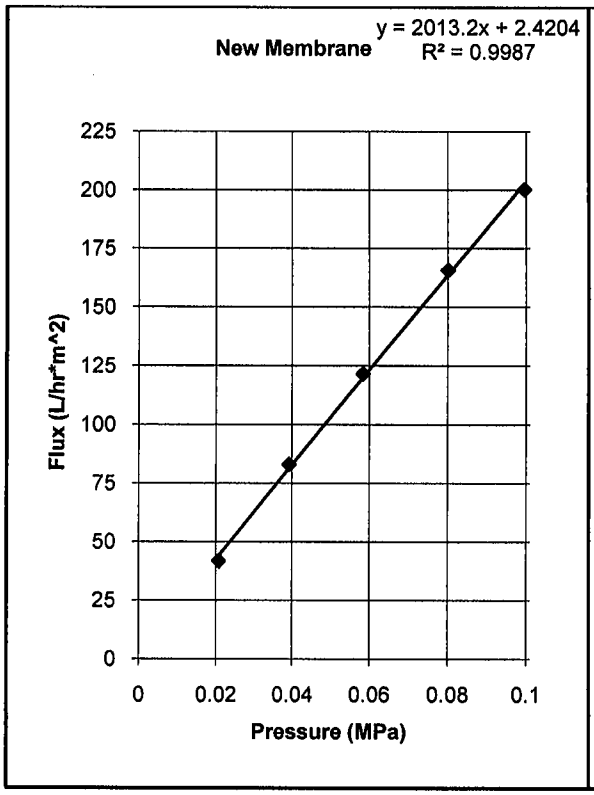
1997.9 0.9959

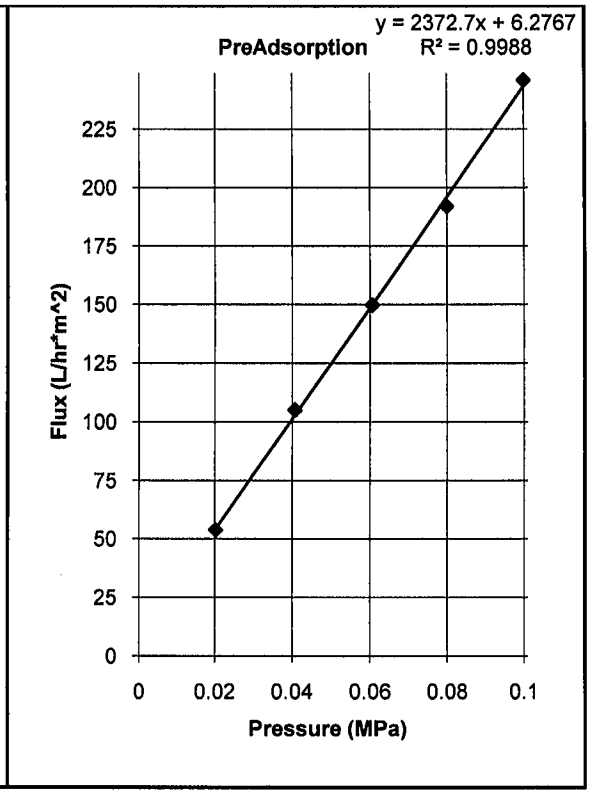
After Cleaning

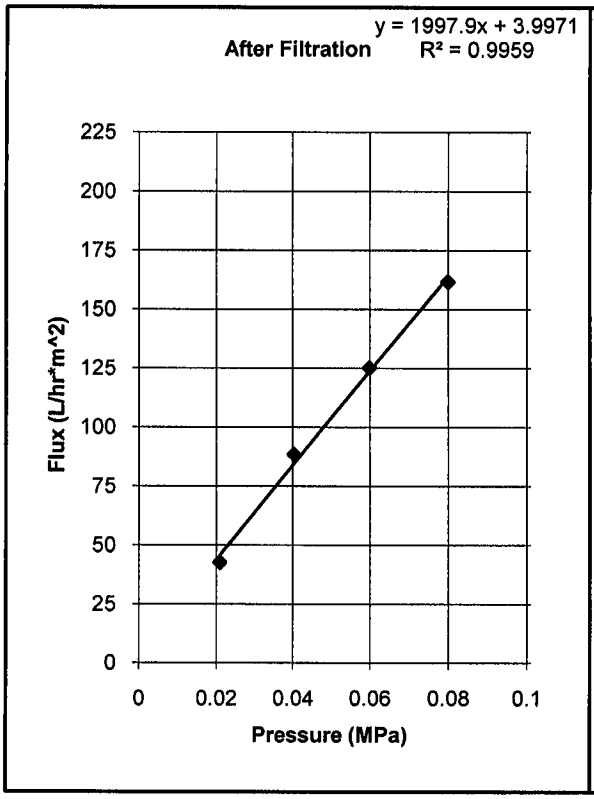
weight (g)	17.871	18.1565	18.7781	19.6593	20.803	22.2115
Δweight (g)		0.2855	0.6216	0.8812	1.1437	1.4085
Time (s)		60	60	60	60	60
Pressure (MPa)		0.0196	0.0401	0.0606	0.081	0.1009
Flux (L/hr*m^2)		41.780488	90.965854	128.9561	167.37073	206.12195

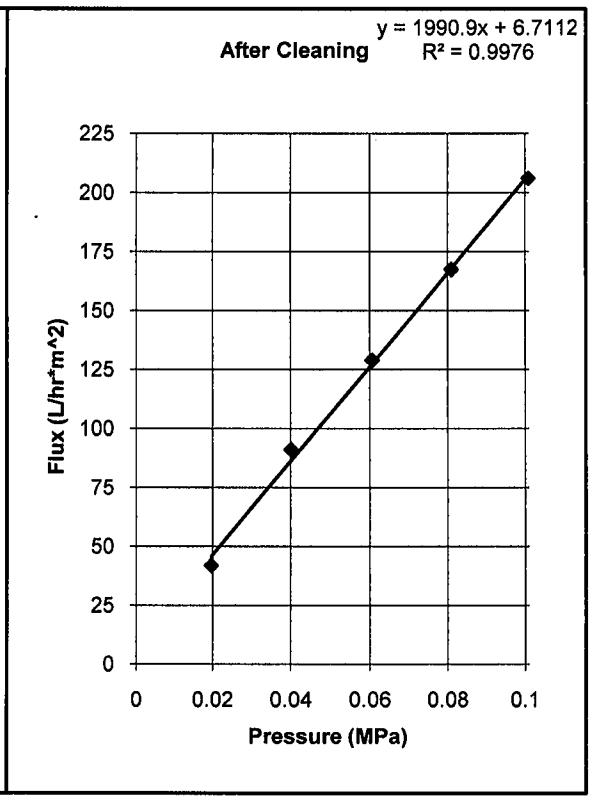
1990 0.9976

	R^2	L_P	ΔL_P
New Membrane	0.9987	2013.2	
PreAdsorption	0.9988	2372.7	359.5
After Filtration	0.9959	1997.9	-374.8
After Cleaning	0.9976	1990	-7.9


y = 2013.2x + 2.4204
New Membrane
R² = 0.9987
Flux (L/hr*m^2)
225
200
175
150
125
100
75
50
25
0
0
0.02
0.04
0.06
0.08
0.1
Pressure (MPa)


y = 2372.7x + 6.2767
PreAdsorption
R² = 0.9988
Flux (L/hr*m^2)
225
200
175
150
125
100
75
50
25
0
0
0.02
0.04
0.06
0.08
0.1
Pressure (MPa)


y = 1997.9x + 3.9971
After Filtration
R² = 0.9959
Flux (L/hr*m^2)
225
200
175
150
125
100
75
50
25
0
0
0.02
0.04
0.06
0.08
0.1
Pressure (MPa)


y = 1990.9x + 6.7112
After Cleaning
R² = 0.9976
Flux (L/hr*m^2)
225
200
175
150
125
100
75
50
25
0
0
0.02
0.04
0.06
0.08
0.1
Pressure (MPa)

R values

Raw Water	Start of Filtration		End of Filtration	
	Prefiltration	Permeate	Prefiltration	Permeate
Absorbance	0.254	0.145	0.35	0.142
TOC	17.66	16.75	22.14	16.12
Rejection (Abs.)	0.429133858		0.594285714	
Rejection (TOC)	0.051528879		0.271906052	

HPI	Start of Filtration		End of Filtration	
	Prefiltration	Permeate	Prefiltration	Permeate
Absorbance	0.072	0.051	0.072	0.05
TOC	17.74	17.38	16.91	16.19
Rejection (Abs.)	0.291666667		0.305555556	
Rejection (TOC)	0.020293123		0.042578356	

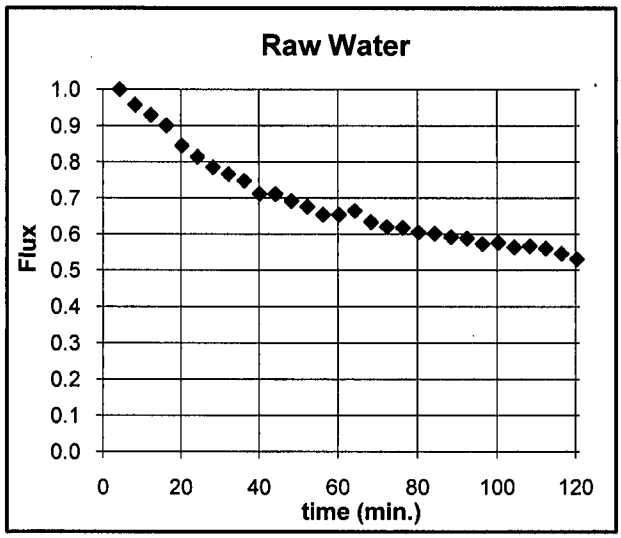
HPO	Start of Filtration		End of Filtration	
	Prefiltration	Permeate	Prefiltration	Permeate
Absorbance	0.104	0.09	0.113	0.091
TOC	8.33	7.9	10.17	8.79
Rejection (Abs.)	0.134615385		0.194690265	
Rejection (TOC)	0.051620648		0.135693215	

8.4 Appendix Part D

Trial data measured for the experimental procedure for modified membranes can be found in this section and consist of 17 pages broken up in the following way:

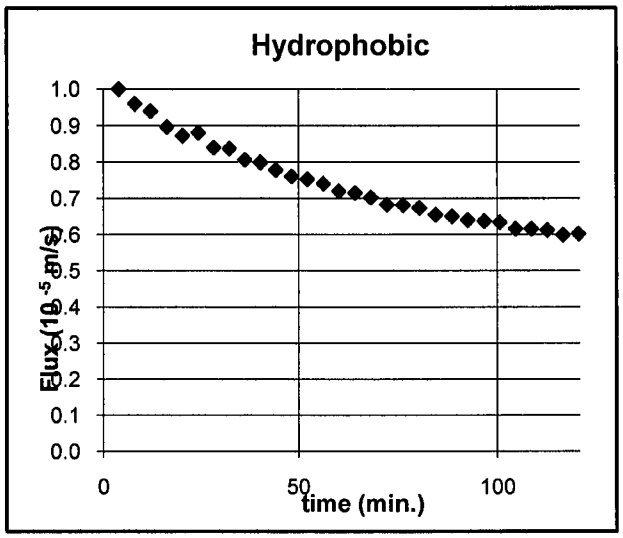
Table of Contents

Sample Number	Flask (g)	Flask + Sample (g)	Sample (g)	Time		Time (min)		Flowrate (g/min)	Flux (10^{-5} m/s)	J/J_O
				Min	Sec	Total	Diff.			
1	18.3217	22.1198	3.7981	4	9	4.15	4.15	0.9152	3.720	1.000
2	17.7636	21.2528	3.4892	8	8	8.13	3.98	0.8759	3.561	0.957
3	18.0121	21.4138	3.4017	12	8	12.13	4.00	0.8504	3.457	0.929
4	17.4694	20.7794	3.3100	16	9	16.15	4.02	0.8241	3.350	0.901
5	17.5806	20.6752	3.0946	20	9	20.15	4.00	0.7737	3.145	0.845
6	17.8434	20.8498	3.0064	24	11	24.18	4.03	0.7454	3.030	0.815
7	18.0884	20.9629	2.8745	28	11	28.18	4.00	0.7186	2.921	0.785
8	17.9095	20.7144	2.8049	32	11	32.18	4.00	0.7012	2.851	0.766
9	18.3856	21.1347	2.7491	36	12	36.20	4.02	0.6844	2.782	0.748
10	17.9699	20.5761	2.6062	40	12	40.20	4.00	0.6516	2.649	0.712
11	18.0200	20.6351	2.6151	44	13	44.22	4.02	0.6511	2.647	0.711
12	17.7076	20.2406	2.5330	48	13	48.22	4.00	0.6333	2.574	0.692
13	17.9128	20.3996	2.4868	52	14	52.23	4.02	0.6191	2.517	0.677
14	17.9717	20.3667	2.3950	56	14	56.23	4.00	0.5988	2.434	0.654
15	17.4759	19.8807	2.4048	60	15	60.25	4.02	0.5987	2.434	0.654
16	18.0298	20.4333	2.4035	64	12	64.20	3.95	0.6085	2.474	0.665
17	18.4088	20.7499	2.3411	68	14	68.23	4.03	0.5804	2.360	0.634
18	18.1034	20.3768	2.2734	72	14	72.23	4.00	0.5684	2.310	0.621
19	17.7785	20.0509	2.2724	76	15	76.25	4.02	0.5657	2.300	0.618
20	18.2955	20.5022	2.2067	80	14	80.23	3.98	0.5540	2.252	0.605
21	18.3206	20.5064	2.1858	84	12	84.20	3.97	0.5510	2.240	0.602
22	17.8488	20.0816	2.2328	88	19	88.32	4.12	0.5424	2.205	0.593
23	18.0205	20.1931	2.1726	92	21	92.35	4.03	0.5387	2.190	0.589
24	17.7682	19.8496	2.0814	96	19	96.32	3.97	0.5247	2.133	0.573
25	18.0009	20.1040	2.1031	100	18	100.30	3.98	0.5280	2.146	0.577
26	18.1818	20.2740	2.0922	104	21	104.35	4.05	0.5166	2.100	0.565
27	17.9426	20.0021	2.0595	108	19	108.32	3.97	0.5192	2.111	0.567
28	17.6502	19.7039	2.0537	112	19	112.32	4.00	0.5134	2.087	0.561
29	18.2562	20.2741	2.0179	116	21	116.35	4.03	0.5003	2.034	0.547
30	18.2164	20.1535	1.9371	120	20	120.33	3.98	0.4863	1.977	0.531

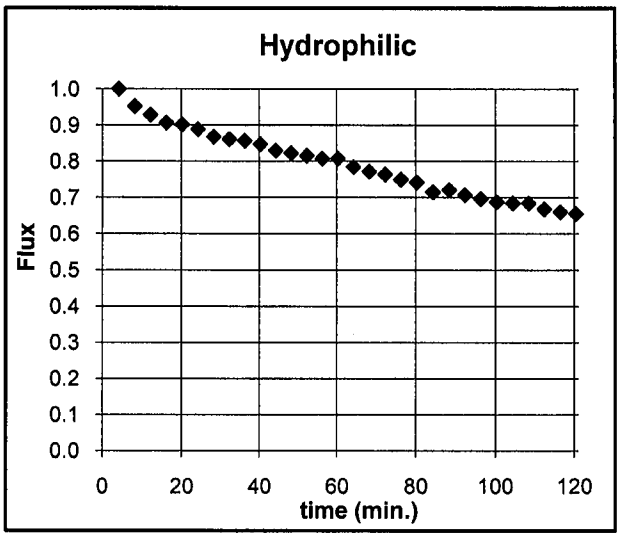


charged HPO

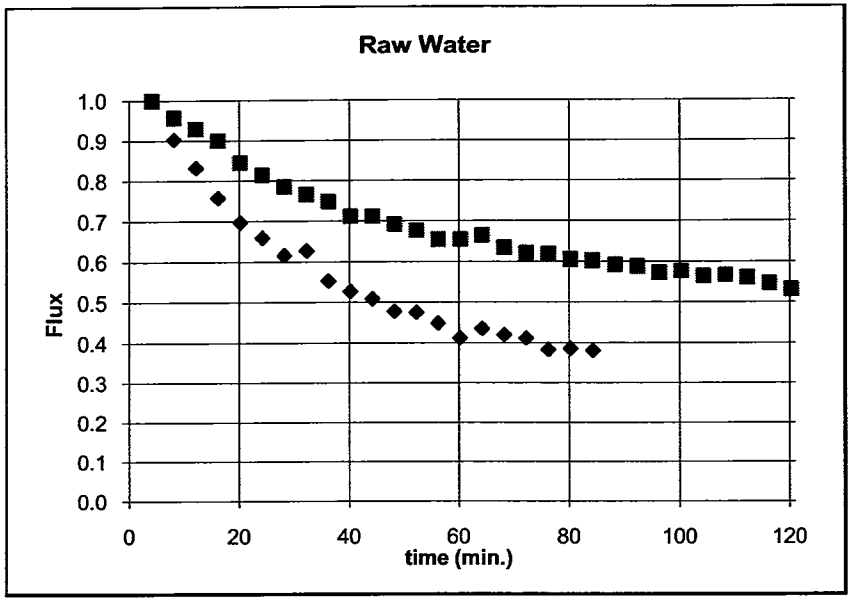
Sample Number	Flask (g)	Flask + Sample (g)	Sample (g)	Time		Time (min)		Flowrate (g/min)	Flux (10^{-5} m/s)	J/J_O
				Min	Sec	Total	Diff.			
2	17.7619	20.8235	3.0616	3	47	3.78	3.78	0.8092	3.290	1.000
3	18.0112	21.1316	3.1204	7	48	7.80	4.02	0.7769	3.158	0.960
4	17.4684	20.5608	3.0924	11	52	11.87	4.07	0.7604	3.091	0.940
5	17.5797	20.5899	3.0102	16	1	16.02	4.15	0.7253	2.949	0.896
6	17.8427	20.6787	2.8360	20	2	20.03	4.02	0.7061	2.870	0.872
7	18.0878	20.9986	2.9108	24	7	24.12	4.08	0.7128	2.898	0.881
8	17.9088	20.6042	2.6954	28	5	28.08	3.97	0.6795	2.762	0.840
9	18.3847	21.1168	2.7321	32	7	32.12	4.03	0.6774	2.754	0.837
10	17.9689	20.5905	2.6216	36	8	36.13	4.02	0.6527	2.653	0.806
11	18.0190	20.6265	2.6075	40	10	40.17	4.03	0.6465	2.628	0.799
12	17.7067	20.2261	2.5194	44	10	44.17	4.00	0.6299	2.560	0.778
13	17.9117	20.3842	2.4725	48	11	48.18	4.02	0.6156	2.502	0.761
14	17.9707	20.4479	2.4772	52	15	52.25	4.07	0.6091	2.476	0.753
15	17.4749	19.9025	2.4276	56	18	56.30	4.05	0.5994	2.437	0.741
16	18.0291	20.3392	2.3101	60	16	60.27	3.97	0.5824	2.367	0.720
17	18.4077	20.7895	2.3818	64	23	64.38	4.12	0.5786	2.352	0.715
18	18.1028	20.3379	2.2351	68	19	68.32	3.93	0.5682	2.310	0.702
19	17.7773	20.0139	2.2366	72	22	72.37	4.05	0.5522	2.245	0.682
20	18.2943	20.5190	2.2247	76	24	76.40	4.03	0.5516	2.242	0.682
21	18.3197	20.5168	2.1971	80	26	80.43	4.03	0.5447	2.214	0.673
22	17.8480	19.9671	2.1191	84	26	84.43	4.00	0.5298	2.154	0.655
23	18.0196	20.1683	2.1487	88	31	88.52	4.08	0.5262	2.139	0.650
24	17.7674	19.8467	2.0793	92	32	92.53	4.02	0.5177	2.104	0.640
25	18.0001	20.1316	2.1315	96	40	96.67	4.13	0.5157	2.096	0.637
26	18.1813	20.1991	2.0178	100	36	100.60	3.93	0.5130	2.085	0.634
27	17.9419	19.9530	2.0111	104	38	104.63	4.03	0.4986	2.027	0.616
28	17.6497	19.6341	1.9844	108	37	108.62	3.98	0.4982	2.025	0.616
29	18.2551	20.2366	1.9815	112	37	112.62	4.00	0.4954	2.014	0.612
30	18.2154	20.1624	1.9470	116	38	116.63	4.02	0.4847	1.970	0.599
31	17.8696	19.8180	1.9484	120	38	120.63	4.00	0.4871	1.980	0.602

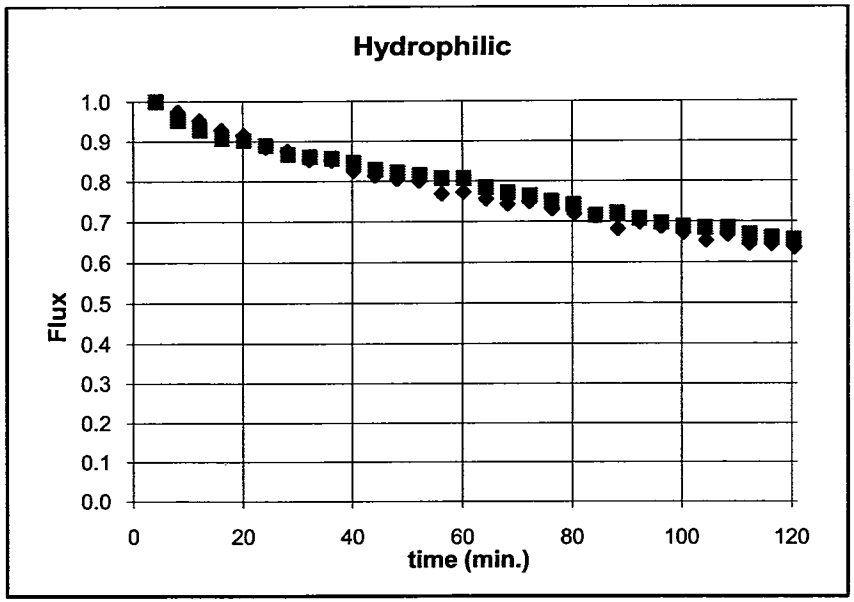


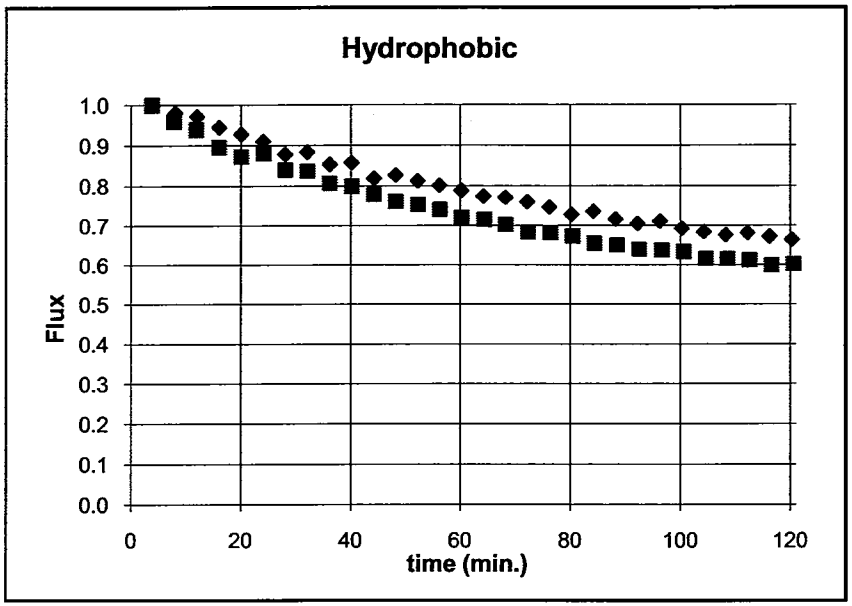
Sample Number	Flask (g)	Flask + Sample (g)	Sample (g)	Time		Time (min)		Flowrate (g/min)	Flux (10^{-5} m/s)	J/J_o
				Min	Sec	Total	Diff.			
1	18.3200	22.7516	4.4316	4	3	4.05	4.05	1.0942	4.448	1.000
2	17.7620	21.9632	4.2012	8	5	8.08	4.03	1.0416	4.234	0.952
3	18.0111	22.0749	4.0638	12	5	12.08	4.00	1.0160	4.130	0.928
4	17.4685	21.4857	4.0172	16	8	16.13	4.05	0.9919	4.032	0.907
5	17.5796	21.5429	3.9633	20	9	20.15	4.02	0.9867	4.011	0.902
6	17.8426	21.7651	3.9225	24	11	24.18	4.03	0.9725	3.953	0.889
7	18.0878	21.9319	3.8441	28	14	28.23	4.05	0.9492	3.858	0.867
8	17.9086	21.6916	3.7830	32	15	32.25	4.02	0.9418	3.829	0.861
9	18.3847	22.1350	3.7503	36	15	36.25	4.00	0.9376	3.811	0.857
10	17.9689	21.6606	3.6917	40	14	40.23	3.98	0.9268	3.767	0.847
11	18.0190	21.6485	3.6295	44	14	44.23	4.00	0.9074	3.689	0.829
12	17.7067	21.3048	3.5981	48	14	48.23	4.00	0.8995	3.657	0.822
13	17.9122	21.4804	3.5682	52	14	52.23	4.00	0.8921	3.626	0.815
14	17.9709	21.5052	3.5343	56	14	56.23	4.00	0.8836	3.592	0.808
15	17.4751	21.0088	3.5337	60	14	60.23	4.00	0.8834	3.591	0.807
16	18.0291	21.4483	3.4192	64	13	64.22	3.98	0.8584	3.489	0.784
17	18.4082	21.7998	3.3916	68	14	68.23	4.02	0.8444	3.432	0.772
18	18.1026	21.4451	3.3425	72	14	72.23	4.00	0.8356	3.397	0.764
19	17.7775	21.0729	3.2954	76	15	76.25	4.02	0.8204	3.335	0.750
20	18.2944	21.5424	3.2480	80	15	80.25	4.00	0.8120	3.301	0.742
21	18.3197	21.4621	3.1424	84	16	84.27	4.02	0.7823	3.180	0.715
22	17.8479	21.0019	3.1540	88	16	88.27	4.00	0.7885	3.205	0.721
23	18.0196	21.1269	3.1073	92	17	92.28	4.02	0.7736	3.145	0.707
24	17.7674	20.8184	3.0510	96	17	96.28	4.00	0.7628	3.101	0.697
25	17.9999	21.0093	3.0094	100	17	100.28	4.00	0.7524	3.058	0.688
26	18.1810	21.1889	3.0079	104	18	104.30	4.02	0.7489	3.044	0.684
27	17.9417	20.9885	3.0468	108	22	108.37	4.07	0.7492	3.046	0.685
28	17.6496	20.5645	2.9149	112	21	112.35	3.98	0.7318	2.975	0.669
29	18.2550	21.1696	2.9146	116	23	116.38	4.03	0.7226	2.938	0.660
30	18.2152	21.0827	2.8675	120	23	120.38	4.00	0.7169	2.914	0.655



comparison







blue=untreated membrane
red=charged membrane

experiment_charged_2008-12-06.xls

New Membrane

weight (g)	18.0499	18.3427	18.8933	19.7498	20.8734	22.2676
Δweight (g)		0.2928	0.5506	0.8565	1.1236	1.3942
Time (s)		60	60	60	60	60
Pressure (MPa)		0.0206	0.04	0.0598	0.0803	0.1
Flux (L/hr*m^2)		42.84878	80.57561	125.34146	164.42927	204.02927

2040.1 0.9994

After Modification

weight (g)	17.6696	17.9649	18.5626	19.4257	20.6013	22.0024
Δweight (g)		0.2953	0.5977	0.8631	1.1756	1.4011
Time (s)		60	60	59	60	60
Pressure (MPa)		0.0202	0.04	0.0601	0.0801	0.0993
Flux (L/hr*m^2)		43.214634	87.468293	128.44812	172.03902	205.03902

2059.2 0.9983

PreAdsorption

weight (g)	17.8667	18.1605	18.6682	19.436	20.4246	21.638
Δweight (g)		0.2938	0.5077	0.7678	0.9886	1.2134
Time (s)		66	64	62	61	61
Pressure (MPa)		0.0215	0.0388	0.0582	0.0788	0.1002
Flux (L/hr*m^2)		39.086475	69.653963	108.73643	142.30148	174.65974

1738.7 0.9971

After Filtration

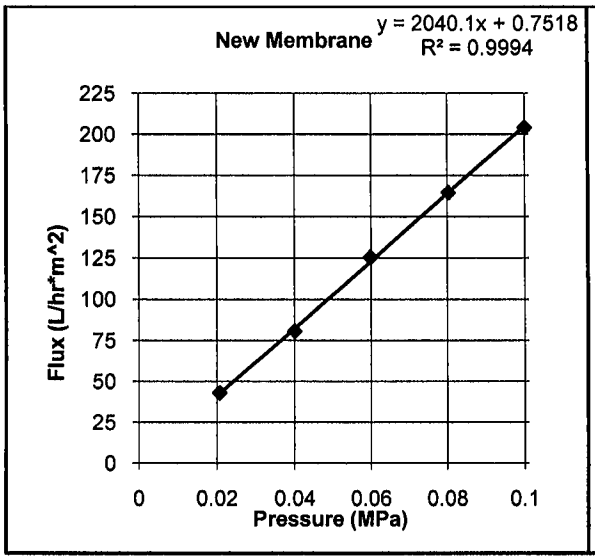
weight (g)	18.0426	18.3415	18.8611	19.6487	20.7068	22.038
Δweight (g)		0.2989	0.5196	0.7876	1.0581	1.3312
Time (s)		60	60	60	60	60
Pressure (MPa)		0.0201	0.0397	0.0595	0.0798	0.0995
Flux (L/hr*m^2)		43.741463	76.039024	115.25854	154.8439	194.80976

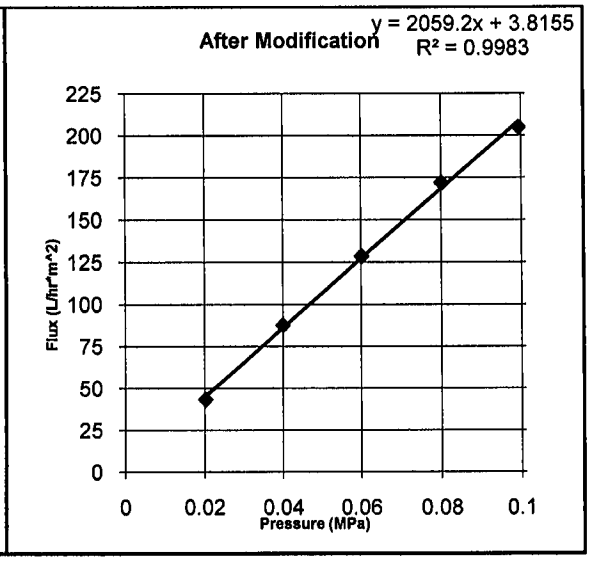
1915.5 0.9987

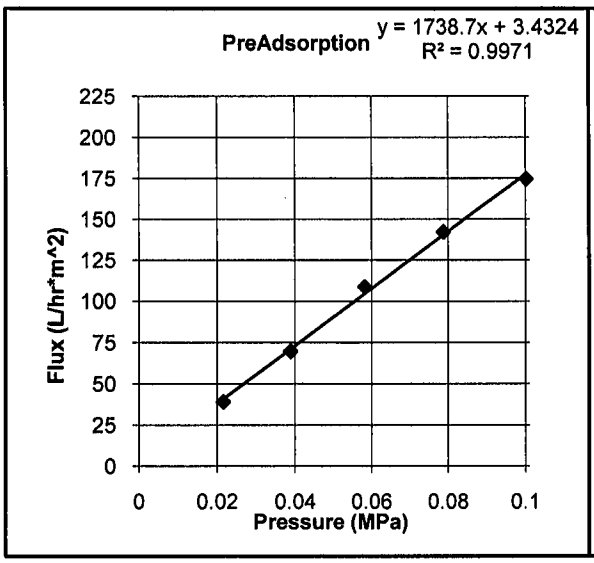
After Cleaning

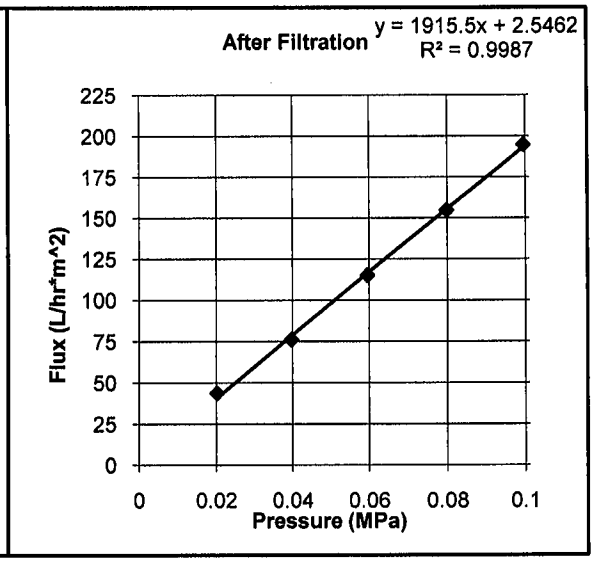
weight (g)	17.8728	18.2313	18.9286	19.8824	21.0959	22.4809
Δweight (g)		0.3585	0.6973	0.9538	1.2135	1.385
Time (s)		60	60	60	60	60
Pressure (MPa)		0.0198	0.0401	0.0602	0.0828	0.0998
Flux (L/hr*m^2)		52.463415	102.0439	139.58049	177.58537	202.68293

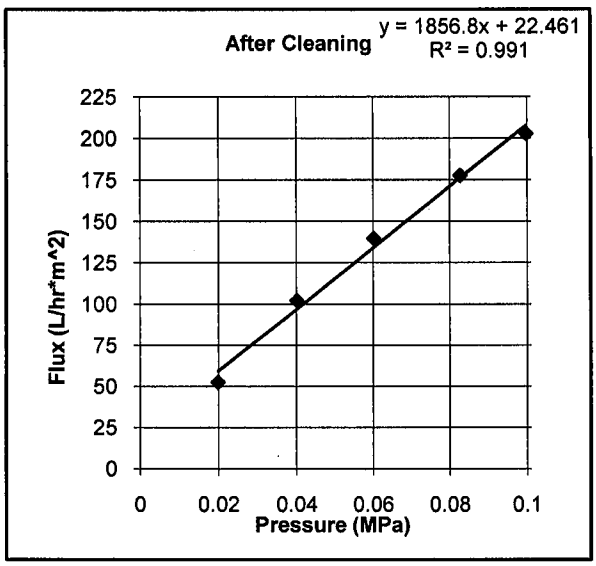
1856.8 0.991











	R^2	L_P
New Membrane	0.9994	2040.1
After Modification	0.9983	2059.2
PreAdsorption	0.9971	1738.7
After Filtration	0.9987	1915.5
After Cleaning	0.9910	1856.8

New Membrane

weight (g)	17.9026	18.1919	18.7301	19.5207	20.5668	21.8839
Δweight (g)		0.2893	0.5382	0.7906	1.0461	1.3171
Time (s)		64	61	59	60	61
Pressure (MPa)		0.0203	0.0394	0.06	0.0799	0.1006
Flux (L/hr*m^2)		39.690549	77.469812	117.65854	153.0878	189.58657

1866.3 0.9992

After Modification

weight (g)	17.8671	18.0768	18.5845	19.2702	20.1351	21.2258
Δweight (g)		0.2097	0.5077	0.6857	0.8649	1.0907
Time (s)		60	65	61	60	60
Pressure (MPa)		0.0198	0.0421	0.0599	0.0786	0.1002
Flux (L/hr*m^2)		30.687805	68.582364	98.701319	126.57073	159.61463

1601 0.999

PreAdsorption

weight (g)	17.8667	18.0802	18.5132	19.1692	20.0068	21.116
Δweight (g)		0.2135	0.433	0.656	0.8376	1.1092
Time (s)		60	62	62	59	63
Pressure (MPa)		0.0203	0.0388	0.0588	0.0794	0.0992
Flux (L/hr*m^2)		31.243902	61.321794	92.903226	124.65316	154.59233

1562.3 0.9998

After Filtration

weight (g)	23.1863	23.4127	23.8766	24.5314	25.4262	26.5161
Δweight (g)		0.2264	0.4639	0.6548	0.8948	1.0899
Time (s)		62	62	58	61	60
Pressure (MPa)		0.0202	0.0404	0.0607	0.0802	0.1
Flux (L/hr*m^2)		32.062943	65.697876	99.12868	128.79968	159.49756

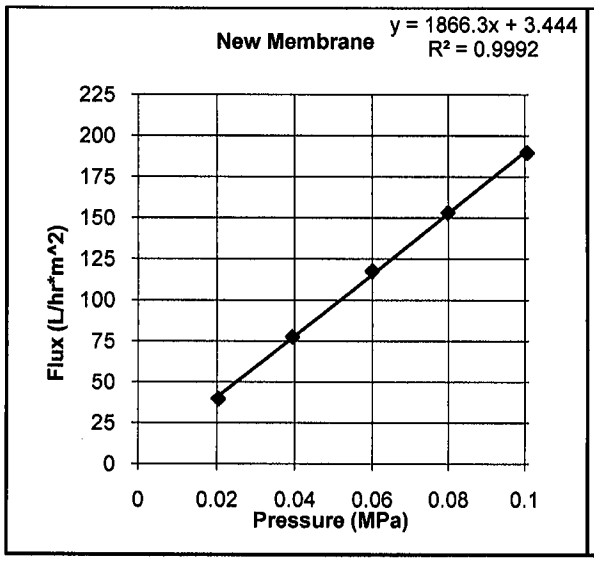
1594.9 0.9996

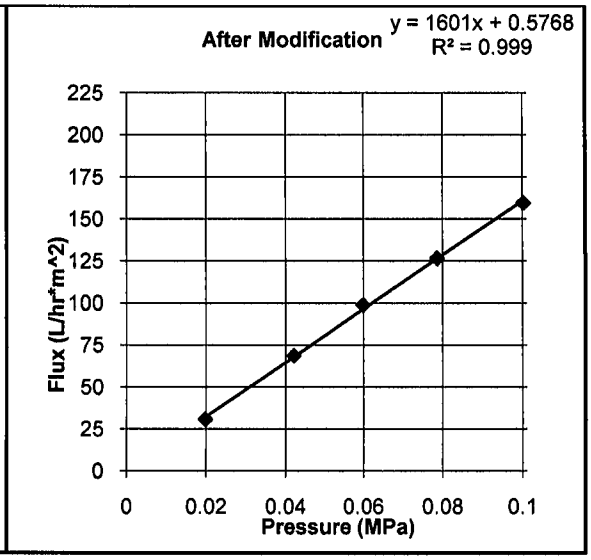
After Cleaning

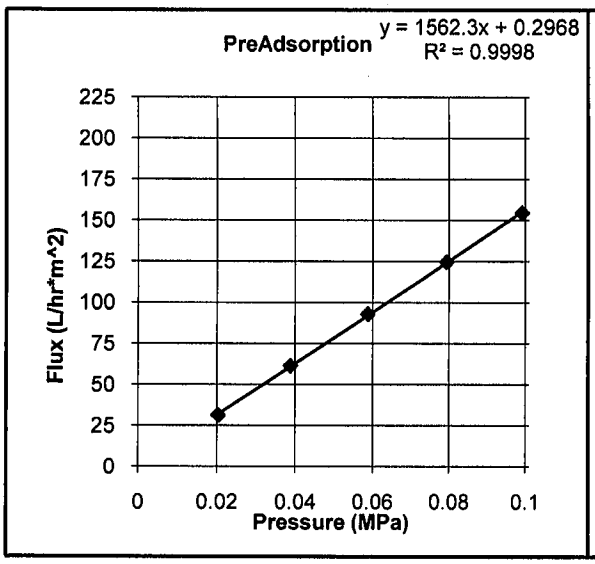
weight (g)	17.8807	18.1033	18.6135	19.3146	20.2571	21.4676
Δweight (g)		0.2226	0.5102	0.7011	0.9425	1.2105
Time (s)		62	61	59	60	61
Pressure (MPa)		0.0189	0.042	0.06	0.0803	0.0999
Flux (L/hr*m^2)		31.524784	73.439424	104.33898	137.92683	174.2423

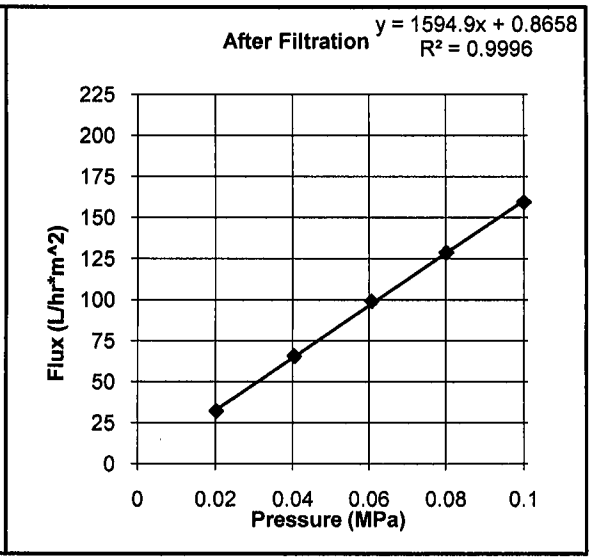
1747.5 0.9997

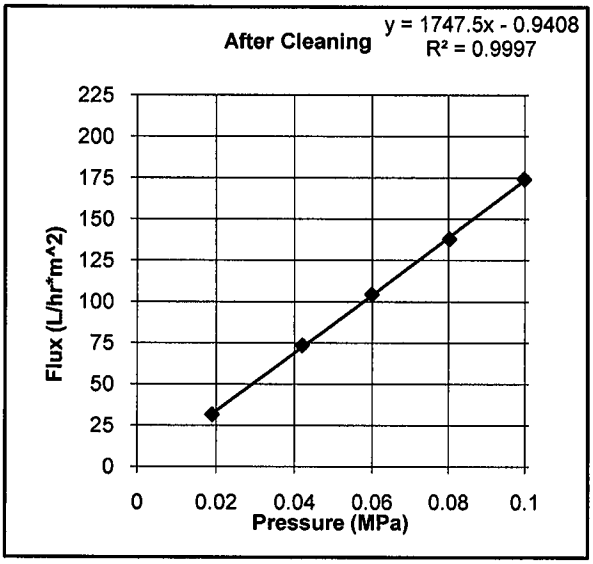
Lp HPO











	R^2	L_P
New Membrane	0.9992	1866.3
After Modification	0.9990	1601
PreAdsorption	0.9998	1562.3
After Filtration	0.9996	1594.9
After Cleaning	0.9997	1747.5

New Membrane

weight (g)	17.8661	18.1778	18.7549	19.5608	20.5979	21.9138
Δweight (g)		0.3117	0.5771	0.8059	1.0371	1.3159
Time (s)		63	60	60	60	60
Pressure (MPa)		0.0224	0.043	0.0602	0.0787	0.1004
Flux (L/hr*m^2)		43.442509	84.453659	117.93659	151.77073	192.57073

1906.8 0.9997

After Modification

weight (g)	17.867	18.1179	18.6692	19.439	20.4279	21.6833
Δweight (g)		0.2509	0.5513	0.7698	0.9889	1.2554
Time (s)		58	62	60	60	62
Pressure (MPa)		0.0209	0.0417	0.0608	0.08	0.0998
Flux (L/hr*m^2)		37.983179	78.075531	112.65366	144.71707	177.79072

1766.3 0.9989

PreAdsorption

weight (g)	17.8669	18.1461	18.6609	19.4531	20.5129	21.7635
Δweight (g)		0.2792	0.5148	0.7922	1.0598	1.2506
Time (s)		63	60	63	62	60
Pressure (MPa)		0.0209	0.0401	0.06	0.0802	0.1002
Flux (L/hr*m^2)		38.912892	75.336585	110.41115	150.08969	183.01463

1826.5 0.9994

After Filtration

weight (g)	17.9324	18.1637	18.6841	19.3521	20.2655	21.379
Δweight (g)		0.2313	0.5204	0.668	0.9134	1.1135
Time (s)		58	64	57	59	60
Pressure (MPa)		0.0202	0.0409	0.0595	0.0801	0.1
Flux (L/hr*m^2)		35.01598	71.396341	102.90116	135.93386	162.95122

1611.5 0.9977

After Cleaning

weight (g)	17.8953	18.1737	18.691	19.451	20.5062	21.7628
Δweight (g)		0.2784	0.5173	0.76	1.0552	1.2566
Time (s)		66	61	60	63	61
Pressure (MPa)		0.02	0.0399	0.06	0.0797	0.0994
Flux (L/hr*m^2)		37.037694	74.461415	111.21951	147.0662	180.87805

1814.2 0.9997